FABRICATION & TRIBOLOGICAL BEHAVIOUR OF FEATHER REINFORCED POLYMER COMPOSITES

Thesis submitted in partial fulfillment of the requirement
For the award of the degree of

Master of Technology (Research)

in

METALLURGICAL AND MATERIALS ENGINEERING

By

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National Institute of Technology, Rourkela
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December- 2009

Dedicated to

My Grand Father

Late Brajabandhu Nayak

Department of Metallurgical & Materials Engineering
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CERTIFICATE

This is to certify that the work in the thesis entitled "***Fabrication & Tribological behaviour of feather reinforced polymer composites***" by **Mr Nadiya Bihary Nayak** in partial fulfillment of the requirements for the award of Master of Technology (Research) degree in **METALLURGICAL AND MATERIALS ENGINEERING** with specialization in **"POLYMER COMPOSITE"** at the National Institute of Technology, Rourkela (Deemed University), is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Prof. Subash Chandra Mishra
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Date:

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Abstract

Natural fibers have recently attracted the attention of scientists and technologists because of the advantages that these fibers provide over conventional reinforcement materials, and for which the development of natural fibers composites has been a subject of interest for the past few years. These natural fibers are low-cost fibers with low density and high specific properties. These are biodegradable and non-abrasive, unlike other reinforcing fibers. However, certain drawbacks such as incompatibility with the hydrophobic polymer matrix, the tendency to form aggregates during processing and poor resistance to moisture greatly reduce the potential of natural fibers to be used as reinforcement in polymer matrices.

In the present piece of research work, we have used short chicken feather fiber (barbicels) which are hollow, tough and light. Short fibers obtained from poultry feathers are found to possess high toughness, good thermal insulation properties, non abrasive behavior and hydrophobic nature. Their low cost, low density and large aspect ratio (of the barbicels) can make them good reinforcing materials in polymer matrix to make composites. This work reports the development of poultry feather reinforced composites with different weight percentage reinforcements. Randomly oriented short feather fibers with different weight percentage i.e. 10%, 20% and 30%, are reinforced into epoxy resin matrix to prepare composite slabs. The dielectric properties of the composites are evaluated at different temperature and frequency ranges. It is found that the dielectric properties are dependent on operating frequency and temperature conditions. Such composites can have a potential use as a low dielectric material for typical applications. Flexural strength, micro hardness, density and porosity of this chicken feather composite are also evaluated.

Solid particle erosion tests are conducted on the composite samples to evaluate their wear resistance. A self developed air-jet type erosion test rig and dry silica sand particles are used for this purpose. It is found that the material loss from the composite

surface depends greatly on operational variables like impact angle, impact velocity and weight percentage of fiber content etc. Taguchi experimental design technique is used in this study to determine the relative significance of various control factors influencing the erosion wear rate. The erosion response of the composite is compared with that of neat epoxy and the effect of fiber reinforcement on the wear rate is discussed.

Experiments have been conducted under laboratory condition to assess the abrasive wear characteristics of the composites under different operating conditions, in pure sliding mode on a pin-on-disc machine. In present investigation, abrasive paper of different grit sizes (100-200μm, 200-300 μm, 300-400 μm) are used for abrasion wear test of feather reinforced composites at dry condition. It was found that the abrasive wear of the composite shows dependence on all the test parameters viz. applied load, sliding speed and abrasive particle size. The size of the abrasive particle and applied load tends to increase abrasive wear volume of the composites, whereas wear rate tends to decrease with increasing sliding velocity at constant applied load for the media having particle of size range 200-300 μm. Secondly, higher weight fraction of short feather fibers in the composite improves the abrasive wear resistance because higher amount of energy is required to facilitate tearing of feather fiber. Scanning electron microscopy is used to observe the worn surfaces and to understand the mechanism involved in the removal of the material.

Tribological (wear) behavior of these composites has been successfully analyzed using experimental design scheme. Two predictive models - one based on Taguchi approach and the other based on artificial neural network analysis (ANN) are proposed. It has been demonstrated that these models reflect the effects of various factors and their predictive results are consistent with theoretical observations.

Keywords: Natural fiber, Short Chicken feather fiber, Dielectric constant, Solid particle erosion wear, Abrasive wear, Taguchi, Artificial neural network.

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Chapter 1

Introduction

Chapter 1
INTRODUCTION

1.1 MOTIVATION

Composites are combinations of two materials in which one of the materials called the reinforcing phase is in the form of fiber sheets or particles and are embedded in the other material called the matrix phase. The primary functions of the matrix are to transfer stresses between the reinforcing fibers/particles and to protect them from mechanical and/or environmental damage whereas the presence of fibers/particles in a composite improves its mechanical properties such as strength, stiffness etc. A composite is therefore a synergistic combination of two or more micro-constituents that differ in physical form and chemical composition and which are insoluble in each other. The objective is to take advantage of the superior properties of both materials without compromising on the weakness of either.

Composite materials have successfully substituted the traditional materials in several light weight and high strength applications. The reasons why composites are selected for such applications are mainly their high strength-to-weight ratio, high tensile strength at elevated temperatures, high creep resistance and high toughness. Typically, in a composite, the reinforcing materials are strong with low densities while the matrix is usually a ductile or tough material. If the composite is designed and fabricated correctly it combines the strength of the reinforcement with the toughness of the matrix to achieve a combination of desirable properties not available in any single conventional material. The strength of the composites depends primarily on the amount, arrangement and type of fiber and /or particle reinforcement in the resin.

1.2 BACKGROUND

The most primitive composite materials were straw and mud combined to form bricks for building construction. The ancient brick-making process can still be seen on Egyptian tomb paintings in the Metropolitan Museum of Art. The most advanced examples perform routinely on spacecraft in demanding environments. The most visible applications pave our roadways in the form of either steel and aggregate reinforced Portland cement or asphalt concrete. Those composites closest to our personal hygiene form our shower stalls and bath tubs made of fiberglass. Solid surface, imitation granite and cultured marble sinks and counter tops are widely used to enhance our living experiences.

The recognition of the potential weight savings that can be achieved by using the advanced composites, which in turn means reduced cost and greater efficiency, was responsible for this growth in the technology of reinforcements, matrices and fabrication of composites. If the first two decades saw the improvements in the fabrication method, systematic study of properties and fracture mechanics was at the focal point in the 60's. There has been an ever-increasing demand for newer, stronger, stiffer and yet lighter-weight materials in fields such as aerospace, transportation, automobile and construction sectors. Composite materials are emerging chiefly in response to unprecedented demands from technology due to rapidly advancing activities in aircrafts, aerospace and automotive industries. These materials have low specific gravity that makes their properties particularly superior in strength and modulus to many traditional engineering materials such as metals. As a result of intensive studies into the fundamental nature of materials and better understanding of their structure property relationship, it has become possible to develop new composite materials with improved physical and mechanical properties. These new materials include high performance composites such as Polymer matrix composites [**1, 2**], Ceramic matrix composites [**3, 4**] and Metal matrix composites [**5**] etc. Continuous advancements have led to the use of composite materials in more and more diversified applications. The importance of composites as engineering materials is reflected by the fact that out of over 1600 engineering materials available in the market today more than 200 are composite [**6**].

1.3 Types of Composite Materials

Broadly, composite materials can be classified into three groups on the basis of matrix material. They are:

a) Polymer Matrix Composites (PMC)

b) Metal Matrix Composites (MMC)

c) Ceramic Matrix Composites (CMC)

a) Polymer Matrix Composites:

Most commonly used matrix materials are polymeric. The reasons for this are twofold. In general the mechanical properties of polymers are inadequate for many structural purposes. In particular their strength and stiffness are low compared to metals and ceramics. These difficulties are overcome by reinforcing other materials with polymers. Secondly the processing of polymer matrix composites need not involve high pressure and doesn't require high temperature. Also equipments required for manufacturing polymer matrix composites are simpler. For this reason polymer matrix composites developed rapidly and soon became popular for structural applications. Polymer composites are used because overall properties of the composites are superior to those of the individual polymers. They have a greater modulus than the neat polymer but aren't as brittle as ceramics.

b) Metal Matrix Composites:

Metal Matrix Composites have many advantages over monolithic metals like higher specific modulus, higher specific strength, better properties at elevated temperatures, and lower coefficient of thermal expansion. Because of these attributes metal matrix composites are under consideration for wide range of applications viz. combustion chamber nozzle (in rocket, space shuttle), housings, tubing, cables, heat exchangers, structural members etc.

c) Ceramic matrix Composites:

Ceramic fibers, such as alumina and SiC (Silicon Carbide) are advantageous in very high temperature applications, and also where environment attack is an issue. Since ceramics have poor properties in tension and shear, most applications as reinforcement are in the particulate form (e.g. zinc and calcium phosphate). Ceramic Matrix Composites

(CMCs) used in very high temperature environments, these materials use a ceramic as the matrix and reinforce it with short fibers, or whiskers such as those made from silicon carbide and boron nitride.

1.4 Types of polymer composites:

Broadly, polymer composites can be classified into two groups on the basis of reinforcing material. They are:

- Fiber reinforced polymer (FRP)
- Particle reinforced polymer (PRP)

a) Fiber Reinforced composite

Common fiber reinforced composites are composed of fibers and a matrix. Fibers are the reinforcement and the main source of strength while matrix glues all the fibers together in shape and transfers stresses between the reinforcing fibers. The fibers carry the loads along their longitudinal directions. Sometimes, filler might be added to smooth the manufacturing process, impact special properties to the composites, and / or reduce the product cost. Common fiber reinforcing agents include asbestos, carbon / graphite fibers, beryllium, beryllium carbide, beryllium oxide, molybdenum, aluminium oxide, glass fibers, polyamide, bio fibers etc. Similarly common matrix materials include epoxy, phenolic resin, polyester, polyurethane, vinyl ester etc. Among these resin materials, polyester is most widely used. Epoxy, which has higher adhesion and less shrinkage than polyesters, comes in second for its high cost.

b) Particle Reinforced composite

Particles used for reinforcing include ceramics and glasses such as small mineral particles, metal particles such as aluminum and amorphous materials, including polymers and carbon black. Particles are used to increase the modules of the matrix and to decrease the ductility of the matrix. Particles are also used to reduce the cost of the composites. Reinforcements and matrices can be common, inexpensive materials and are easily processed. Some of the useful properties of ceramics and glasses include high melting temp., low density, high strength, stiffness, wear resistance, and corrosion resistance. Many ceramics are good electrical and thermal insulators. Some ceramics have special properties; some ceramics are magnetic materials; some are piezoelectric materials; and a few special ceramics are even superconductors at very low temperatures. Ceramics and glasses have one major drawback: they are brittle. An example of particle – reinforced composites is an automobile tire, which has carbon black particles in a matrix of poly-isobutylene elastomeric polymer.

Over the past few decades, we find that polymers have replaced many of the conventional metals/materials in various applications. This is possible because of the advantages polymers offer over conventional materials. The most important advantages of using polymers are the ease of processing, productivity and cost reduction. Polymer composites have generated wide interest in various engineering fields, particularly in aerospace applications. Research is underway worldwide to develop newer composites with varied combinations of fibers and fillers so as to make them useable under different operational conditions. In most of these applications, the properties of polymers are modified using fillers and fibers to suit the high strength/high modulus requirements. Fiber-reinforced polymers offer advantages over other conventional materials when specific properties are compared. These composites are finding applications in diverse fields from appliances to spacecrafts.

1.5 Bio Fiber Reinforced Composites

A bio-composite is a material formed by a matrix (resin) and a reinforcement of bio fibers (usually derived from plants or cellulose). With wide-ranging uses from environment-friendly biodegradable composites to biomedical composites for drug/gene delivery, tissue engineering applications and cosmetic orthodontics, they often mimic the structures of the living materials involved in the process in addition to the strengthening properties of the matrix that was used but still providing bio compatibility. Bio-composites are characterized by the fact that the bolsters (glass or carbon fiber or talc) are replaced by bio fiber (wood fibers, hemp, flax, sisal, jute...). These bio/bio-fiber composites (bio-Composites) are emerging as a viable alternative to glass-fiber reinforced composites especially in automotive and building product applications. The combination of bio-fibers such as kenaf, hemp, flax, jute, henequen, pineapple leaf fiber, and sisal with polymer matrices from both nonrenewable and renewable resources to produce composite materials that are competitive with synthetic composites requires special attention. Bio fiber–reinforced polypropylene composites have attained commercial attraction in automotive industries. Bio fiber-polypropylene or bio fiber-polyester composites are not sufficiently eco-friendly because of the petroleum-based source and the non-biodegradable nature of the polymer matrix. Using bio fibers with polymers based on renewable resources will allow many environmental issues to be solved. By embedding bio-fibers with renewable resource–based biopolymers such as cellulosic plastics; polylactides; starch plastics; polyhydroxyalkanoates (bacterial polyesters); and soy-based plastics, the so-called green bio-composites are continuously being developed.

1.6 Bio Fibers

Bio fibers have recently attracted the attention of scientists and technologists because of the advantages that these fibers provide over conventional reinforcement materials, and the development of bio fiber composites has been a subject of interest for the past few years. These bio fibers have low-cost with low density and high specific properties. These are biodegradable and nonabrasive, unlike other reinforcing fibers. Also, they are readily available and their specific properties are comparable to those of other fibers used for reinforcements. However, certain drawbacks such as incompatibility with the hydrophobic polymer matrix, the tendency to form aggregates during processing, and poor resistance to moisture limit the potential of bio-fibers to be used as reinforcement in polymers **[7-11]**. Another important aspect is the thermal stability of these fibers. These fibers are lingo-cellulosic and consist of mainly lignin, hemi-cellulose, and cellulose. The cell walls of the fibers undergo pyrolysis with increasing processing temperature and contribute to char formation. These charred layers help to insulate the lingo- cellulosic from further thermal degradation. Since most thermoplastics are processed at high temperatures, the thermal stability of the fibers at processing temperatures is important. Thus the key issues in development of bio reinforced composites are

(i) Thermal stability of the fibers,

(ii) Surface adhesion characteristics of the fibers, and

(iii) Dispersion of the fibers in the case of thermoplastic composites.

1.7 Types of Bio Fibers

Bio fibers are grouped into three types: seed hair, bast fibers, and leaf fibers, depending upon the source. Some examples are cotton (seed hairs), ramie, jute, and flax (bast fibers), and sisal and abaca (leaf fibers). Of these fibers, jute, ramie, flax, and sisal are the most commonly used fibers for polymer composites. On the basis of the source which they are derived from bio fibers can also be grouped as:

- Fibers obtained from plant/vegetable. (cellulose: sisal, jute, abaca, bagasse)
- Fibers obtained from mineral. (minerals: asbestos)
- Fibers derived from animal species. (sheep wool, goat hair, cashmere, rabbit hair, angora fiber, horse hair)
- Fibers from bird / aqueous species. (feather, sea snels etc.)

Numerous reports are available on the bio fiber composites. The research works on development of bio/bio-fiber reinforced polymer composites have been extensively reviewed also **[12]**. Many researchers have been conducted to study the mechanical properties, especially interfacial performances of the composites based on bio fibers due to the poor interfacial bonding between the hydrophilic bio fibers such as sisal, jute and palm fibers and the hydrophobic polymer matrices.

1.8 Mechanical Properties of Bio Fibers

As can be seen from Table 1, the tensile strength of glass fibers is substantially higher than that of bio fibers even though the modulus is of the same order. However, when the specific modulus of bio fibers (modulus/specific gravity) is considered, the bio fibers show values that are comparable to or better than those of glass fibers. These higher specific properties are one of the major advantages of using bio fiber composites for applications wherein the desired properties also include weight reduction.

Fiber	Specific Gravity	Tensile Strength (MPa)	Modulus (GPa)	Specific Modulus
Jute	1.3	393	55	38
Sisal	1.3	510	28	22
Flax	1.5	344	27	50
Sunhemp	1.07	389	35	32
Pineapple	1.56	170	62	40
Glass fiber-E	2.5	3400	72	28

Table 1.1 Mechanical Properties of Bio Fibers (Source Ref. **9**).

1.9 Tribological Behavior of Composite

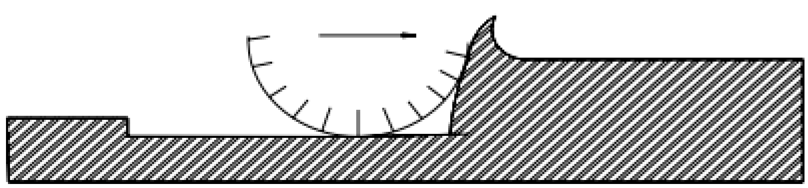
Tribology comes from Greek word tribos, to rub; friction is derived from the Latin verb fricare, which has same meaning. Tribology is the science and technology of interacting surfaces in relative motion or more simple expressed the study of friction, wear and lubrication. The study and evaluation of frication are driven by need to control it. A progressive loss of material from its surface is called wear. It is a material response to the external stimulus and can be mechanical or chemical in nature. Wear is unwanted and the effect of wear on the reliability of industrial components is recognized widely; also, the cost of wear has also been recognized to be high. Systematic efforts in wear research were started in the 1960's in industrial countries. The direct costs of wear failures, i.e., wear part replacements, increased work and time, loss of productivity, as well as indirect losses of energy and the increased environmental burden, are real problems in everyday work and business. In catastrophic failures, there is also the possibility of human losses. Although wear has been extensively studied scientifically, in the 21st century there are still wear problems present in industrial applications. This actually reveals the complexity of the wear phenomenon.

1.10 TYPES OF WEAR

In most basic wear studies where the problems of wear have been a primary concern, the so-called dry friction has been investigated to avoid the influences of fluid lubricants. Dry friction' is defined as friction under not intentionally lubricated conditions but it is well known that it is friction under lubrication by atmospheric gases, especially by oxygen [**13].** A fundamental scheme to classify wear was first outlined by Burwell and Strang **[14].** Later Burwell **[15]** modified the classification to include five distinct types of wear, namely (1) Abrasive, (2) Adhesive, (3) Erosive, (4) Surface fatigue and (5) Corrosive.

1.10.1 Abrasive Wear

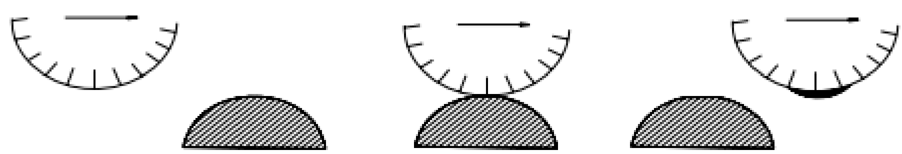
Abrasive wear can be defined as wear that occurs when a hard surface slides against and cuts groove from a softer surface. It can be account for most failures in practice. Hard particles or asperities that cut or groove one of the rubbing surfaces produce abrasive wear. This hard material may be originated from one of the two rubbing surfaces. In sliding mechanisms, abrasion can arise from the existing asperities on one surface (if it is harder than the other), from the generation of wear fragments which are repeatedly deformed and hence get work hardened for oxidized until they became harder than either or both of the sliding surfaces, or from the adventitious entry of hard particles, such as dirt from outside the system.



Two body abrasive wear occurs when one surface (usually harder than the second) cuts material away from the second, although this mechanism very often changes to three body abrasion as the wear debris then acts as an abrasive between the two surfaces. Abrasives can act as in grinding where the abrasive is fixed relative to one surface or as in lapping where the abrasive tumbles producing a series of indentations as opposed to a scratch. According to the recent tribological survey, abrasive wear is responsible for the largest amount of material loss in industrial practice **[16].**

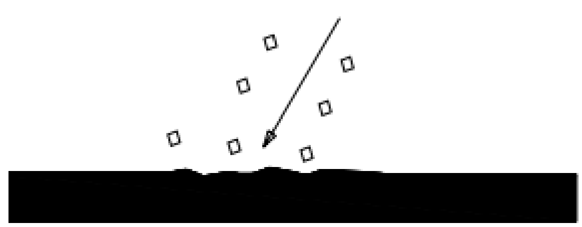
1.10.2 Adhesive Wear

Adhesive wear can be defined as wear due to localized bonding between contacting solid surfaces leading to material transfer between the two surfaces or the loss from either surface. For adhesive wear to occur it is necessary for the surfaces to be in intimate contact with each other. Surfaces, which are held apart by lubricating films, oxide films etc. reduce the tendency for adhesion to occur.



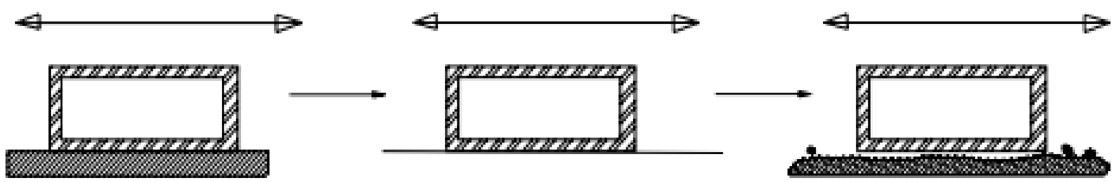
1.10.3 Erosive Wear

Erosive wear can be defined as the process of metal removal due to impingement of solid particles on a surface. Erosion is caused by a gas or a liquid, which may or may not carry, entrained solid particles, impinging on a surface. When the angle of impingement is small, the wear produced is closely analogous to abrasion. When the angle of impingement is normal to the surface, material is displaced by plastic flow or is dislodged by brittle failure.



1.10.4 Surface Fatigue Wear

Wear of a solid surface caused by fracture arising from material fatigue. The term 'fatigue' is broadly applied to the failure phenomenon where a solid is subjected to cyclic loading involving tension and compression above a certain critical stress. Repeated loading causes the generation of micro cracks, usually below the surface, at the site of a pre-existing point of weakness. On subsequent loading and unloading, the micro crack propagates. Once the crack reaches the critical size, it changes its direction to emerge at the surface, and thus flat sheet like particles is detached during wearing. The number of stress cycles required to cause such failure decreases as the corresponding magnitude of stress increases. Vibration is a common cause of fatigue wear.



1.10.5 Corrosive wear

Most metals are thermodynamically unstable in air and react with oxygen to form an oxide, which usually develop layer or scales on the surface of metal or alloys when their interfacial bonds are poor. Corrosion wear is the gradual eating away or deterioration of unprotected metal surfaces by the effects of the atmosphere, acids, gases, alkalis, etc. This type of wear creates pits and perforations and may eventually dissolve metal parts.

1.11 Dielectric properties of natural fiber composite

Dielectric is an insulating material or a very poor conductor of electric current. Dielectric material has no loosely bound electrons, and so no current flows through them. When they are placed in an electric field, the positive and negative charges within the dielectric are displaced minutely in opposite directions, which reduce the electric field within the dielectric material. Examples of dielectrics include glass, plastics, ceramics and polymer composites.

Composites reinforced with natural fibers are an attractive option due to their low cost, low density, biodegradability and low environmental concerns. Natural fibre reinforced polymer matrix composites are being considered for use in several industrial applications. The dielectric constant of a material depends upon the polarizability of its molecules and is determined by different contributions: interfacial, dipole, atomic and electronic polarizations. Atomic and electronic polarizations are instantaneous and do not affect the dependency of the dielectric constant on frequency. Dipole polarization is due to the presence of polar groups in the matrix and fibers. Also, composites are heterogeneous and interfacial polarization exists. Interfacial polarization influences the dielectric properties at very low frequencies and usually decreases with increasing frequency **[17-18].**

1.12 Thesis Outline

The remainder of this thesis is organized as follows

Chapter 2:

Includes a literature review designed to provide a summary of the base of knowledge already available involving the issues of interest.

Chapter 3:

Includes a detailed description of the raw materials, test procedures, and design of experiments methodology.

Chapter 4:

Results and discussion

Section: 1	physico - mechanical properties of composites.
Section: 2	study of erosion wear behavior.
Section: 3	study of abrasion wear behavior.

Chapter 5:

Provides the thesis summary conclusions and recommendation for future work.

Chapter 2

Literature Review

Chapter 2
LITERATURE SURVEY

This chapter deals with the literature survey of the broad topic of interest namely the development of surface modification technology for tribological applications. This treatise embraces chicken feather reinforced epoxy composite and their characteristics. The wear resistance performances of these natural keratin fiber composites have been reviewed critically along with the corresponding failure mechanisms. It also presents a review of the efforts that have been directed worldwide towards management issues of utilization, storage and disposal of feather fiber, which is the material of interest in this work.

2.1 Natural Bio-Fiber Reinforced Composites

Synthetic fibers such as glass, nylon, carbon, Kevlar and boron are generally used to make composite materials for specific purposes even though they are expensive and are non-renewable resources. This is because of their very high specific strength properties which do not deteriorate appreciably with time. On the other hand, there is a growing interest in the development of new materials which enhance optimal utilization of natural resources, and particularly, of renewable resources. The natural fibers like cotton, jute and sisal have also attracted the attention of scientists and technologists for applications in consumer goods, low cost housing and civil structures where the prohibitive cost of synthetic fibers restricts their use [**19-22**]. These natural fiber composites possess characteristic properties such as high electrical and impact resistance, good thermal and acoustic insulating properties and high work of fracture in addition to specific strengths comparable to synthetic fiber reinforced polymer composites [**23**]. Accordingly, manufacturing of high-performance engineering materials from renewable resources has been pursued by researchers across the world owning to renewable raw materials are environmentally sound and do not cause health problem. A substantial increase in the agricultural by-products and wastes of different types has attracted many researchers to develop and characterize new and low-cost materials from renewable local resources [**24**]. As a result, composites made from non-traditional materials obtained directly from agro-wastes such as coir fibre, coconut pith, jute sticks, ground nut husk, rice husk, reed, and straw became one of the main interests of researchers [**25-28**].

They are high specific strength and modulus materials, low priced, recyclable and are easily available. Some experimental techniques, from micro scale to macro scale, such as single fiber pull-out test, single fiber fragmentation test, short beam shear test etc. have been employed to evaluate the interfacial performances of this kind of composites. It is known that natural fibers are non-uniform with irregular cross sections which make their structures quite unique and much different with man-made fibers such as glass fibers, carbon fibers etc. Saheb and Jog [**29]** have presented a very elaborate and extensive review on the reported work on natural fiber reinforced composites with special reference to the type of fibers, matrix polymers, treatment of fibers and fiber-matrix interface. A number of investigators [**30**] have studied the processing, mechanical properties and SEM analysis of novel low cost jute fiber composites. Many researchers have been conducted to study the mechanical properties, especially interfacial performances of the composites based on natural fibers due to the poor interfacial bonding between the hydrophilic natural fibers such as sisal, jute and palm fibers and the hydrophobic polymer matrices. Worldwide laboratories have worked on this topic [**31-34**]. But reports on composites using fibers like poultry feather are rare.

The matrix phase plays a crucial role in the performance of polymer composites. Both thermosets and thermoplastics are attractive as matrix materials for composites. In thermoset composites, formulation is complex because a large number of components are involved such as base resin, curing agents, catalysts, flowing agents, and hardeners. These composite materials are chemically cured to a highly cross-linked, three-dimensional network structure [**35**]. These cross-linked structures are highly solvent resistant, tough, and creep resistant. The fiber loading can be as high as 80% and because of the alignment of fibers; the enhancement in the properties is remarkable. Thermoplastics offer many advantages over thermoset polymers. One of the advantages of thermoplastic matrix composites is their low processing costs. Another is design flexibility and ease of molding complex parts. Simple methods such as extrusion and injection molding are used for processing of these composites. In thermoplastics most of the work reported so far deals with polymers such as polyethylene, polypropylene, polystyrene, and poly (vinyl chloride). This is mainly because the processing temperature is restricted to temperatures below 2007 ^{0}C to avoid thermal degradation of the natural fibers. For thermoplastic composites, the dispersion of the fibers in the composites is also an important parameter to achieve consistency in the product. Thermoplastic composites are flexible and tough and exhibit good mechanical properties [**36**]. However, the percentage of loading is limited by the process ability of the composite. The fiber orientation in the composites is random and accordingly the property modification is not as high as is observed in thermoset composites. Properties of the fibers, the aspect ratio of the fibers, and the fiber–matrix interface govern the properties of the composites. The surface adhesion between the fiber and the polymer plays an important role in the transmission of stress from matrix to the fiber and thus contributes toward the performance of the composite [**37**]. Another important aspect is the thermal stability of these fibers. Since most thermoplastics are processed at high temperatures, the thermal stability of the fibers at processing temperatures is important. Thus the key issues in development of natural reinforced composites are (i) thermal stability of the fibers, (ii) surface adhesion characteristics of the fibers, and (iii) dispersion of the fibers in the case of thermoplastic composite.

2.2 Chicken Feathers

Chicken feather fiber (CFF) has attracted much attention to different product design and engineering industries recently, so as the use of CFF as reinforcements for polymer-based biodegradable materials has emerged gradually. The advantages of using this natural fiber over traditional reinforcing fibers in bio-composites are low cost, low density, acceptable specific strength, recyclability, bio-degradability etc. Because of its renewable and recyclable characteristics, this has been appreciated as a new class of reinforcement for polymer-based bio-composites. In fact, a CFF is made up of two parts, the fibers and the quills (Fig.2.1). The fiber is thin filamentous materials that merge from the middle core material called quills. The feather is basically made up of keratin which contains ordered α-helix or β-helix structure and some disordered structure. The feather fiber fraction has slightly more α -helix over β-helix structure. The outer quill has more β-helix than α-helix structure [**38**]. In simple terms, the quill is hard, central axis off which soft, interlocking fibers branch. Chicken feather are approximately 91% protein (keratin), 1% lipids and 8% water [**39**].

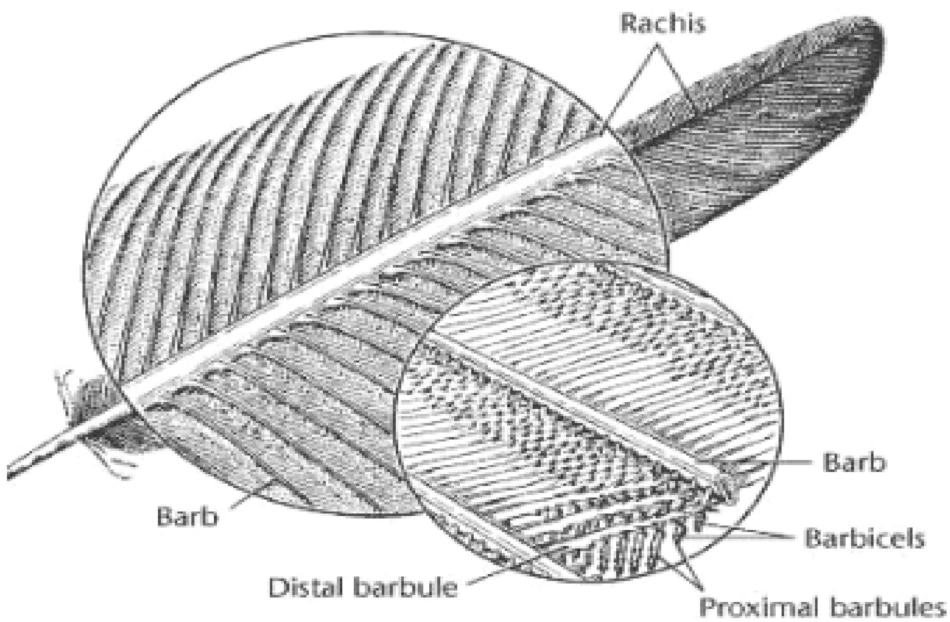


Fig.2.1. Different parts of chicken feather.

The amino acid sequence of chicken feather is very similar to that of other feathers. The sequence is largely composed of cystine, glycine, proline, and serine, and contains almost no histidine, lysine, or methonine [**40**]. The amino acid content of keratin is characterized by a high cystine, which may vary between 2 to 18 wt %. Keratin is insoluble in water, acids, as well as organic solvents, but when it was treated with alkali solution like sodium hydroxide at high concentration, the amide bonds present in keratin are hydrolyzed to form free amine and free carboxylic acid solution [**41**]. The disulfide bonds which formed between two cysteines are responsible for the high strength of keratin, and not hydrolyzed by alkali solution [**42**]. The density of chicken feathers is about 0.8 g/cm3 compared to about 1.5 g/cm3 for cellulose fibers and about 1.3 g/cm3 for wool [**43, 44**]. Smaller feathers have a greater proportion of fiber, which has a higher aspect ratio than the quill. The presence of quill among fibers results in a more granular, lightweight, and bulky material. A typical quill has dimensions on the order of centimeters (length) by millimeters (diameter). Fiber diameters were found to be in the range of 5–50 µm. The density of CFF is lighter than other synthetic and natural reinforcements, thus, CFF inclusion in a composite could potentially lower the composite density, whereas the density of a typical composite with synthetic reinforcement increases as fiber content increases. Hence, light weight composite materials can be produced by inclusion of CFF to polymers which also reduces the transportation cost.

The moisture content of CFF is an important factor that can highly influence their weight and mechanical properties. The moisture content of processed CFFs can vary depending upon processing and environmental conditions. The glass transition temperature (Tg) of the feather fibers and inner quills is approximately 235 ^{0}C while an outer quills is 225 ^{0}C. High Tg represents that a tighter keratin structure is formed to which water is more strongly bonded [**45**]. Fibers and inner quills do not begin to lose water below 100 ^{0}C. The moisture evolution temperature of the CFF and quill occurs in the range of 100–110 ^{0}C. This suggests that it may be possible to have a fully dry fibers and inner quills at 110 ^{0}C. The length and diameter (sometime in the form of bundles) of CFF would highly affect their properties and impregnatability of resin into a resultant composite. Short or longer fibers would highly affect the stress transferability as well as shear strength of the composites. The fibers, themselves also would be a barrier to the movement of polymer chains inside the composites and it may result in increasing their strength and thermal properties, but reduce their fracture toughness. It was found that the development of chicken feather fiber bio-composites have been increasing in recent years, and the outcome are expected to be able to alleviate the global waste problem. One of the advantages of feather fiber is that they are natural fibers and thus can be used in applications where biodegradability is desirable. One such application is erosion control fabrics, which help to stabilize soil and prevent erosion. These fabrics are placed on top of the soil and are usually stapled into the ground to prevent movement.

2.3 Dielectric properties of fiber reinforced polymer composite.

The potential of fiber reinforced polymer composites was recognized more than 50 years ago, now they can find their applications in almost every industry including construction, aerospace, automotive, and electronics. It is well known that, the purpose of the composites is to exhibit enhanced properties that the individual constituents do not have. Usually the research and development in this area are focused on the improvement of the strength and other mechanical properties of polymers composites [**46-48**] less attention has been paid to obtain information on electrical properties. For instance, from the combination of deferent fibers or fillers with polymer matrices one can produce polymer-matrix composites, a material important to the electronic industry for its dielectric properties in the use of capacitors [**49-51**]. The effective utilization of filled polymers depends strongly on the ability to disperse the fillers homogeneously throughout the matrix [**52**]. The interface properties also strongly affect the characteristics and performance of these composites [**53**]. One of the most attractive features of these filled composites is that their dielectric properties can be widely changed by choice of shape, size, and the conductivity of filled constituents in the polymeric matrix. Most of the interesting properties of polymers are attributable to the complex motions within their molecular matrix. In the polymeric system, molecular relaxations exhibit various transitions [**54**]. Actually, the reinforcing composites possess not only mechanical properties superior to those of the matrix, but in all cases higher thermal conductivities and dissimilar electrical properties [**55-58**]. The thermal and dielectric properties of the composites are vital to application is microelectronic industry [**59**].

Composite materials are increasingly used for dielectric applications, i.e., applications that make use of electrically insulating or nearly insulating behavior. This is because of the need of the electronic industry for dielectric materials in electrical insulation, encapsulation, substrates, interlayer dielectrics in a multilayer ceramic chip carrier, printed circuit boards, and capacitors, and because of the rising importance of smart structures that use dielectric materials for piezoelectric, ferroelectric, and pyroelectric devices that provide sensing, actuation, etc. The dielectric constant of a material depends upon the polarizability of its molecules and is determined by different contributions: interfacial, dipole, atomic and electronic polarizations. Atomic and electronic polarizations are instantaneous and do not affect the dependency of the dielectric constant on frequency. Dipole polarization is due to the presence of polar groups in the matrix and fibres. Also, composites are heterogeneous and interfacial polarization exists. Interfacial polarization influences the dielectric properties at very low frequencies and usually decreases with increasing frequency [**60, 61**].

Chicken feather (CF) is an inconvenient and a troublesome waste product of the poultry industry. The feather basically contains keratin that has ordered **α-** helix or **β-** helix structure. Feather fiber/fibrils with an alpha helix structure at the molecular level are light and tough enough to withstand both mechanical and thermal stress. Due to the hollow structure of the fiber, a given volume of fiber innately contains a significant volume of air resulting in low density, 0.80 g/cm3, and low dielectric constant. These fibrils have an aspect ratio >1000. The nodes and hooks in the hollow structure improve the structural properties and increase the surface area. Low strength of such composites restricts their use for structural application [**62, 63**]. However, less emphasis has been paid to obtain information on thermal and electric properties of such composites. The low dielectric constant of the insulator used as printed circuit boards increases the operating speed, minimizes the cross-talk effects between metal interconnects, and diminishes the power consumption as well [**64**]. Development of low k-dielectric material is considered to be one of the main issues in modern high-speed microelectronics [**65**]. Developing a low dielectric material from enable resources, such as CF fiber, is quite attractive from an economic and environmental point of view. Due to hollow structure of the fiber, a given volume of the fiber innately contains a significant volume of cavities. It is known that air is an ideal dielectric material having minimum dielectric constant of ~1.0 for which signals can travel faster [**66**]. Air, for instance, allows the fastest movement of all because it provides essentially no resistance. When traveling near solids, however, the movement tends to kick up opposing positive charges and charges can distract the signal from completing its appointed rounds [**67**]. In the present study, we have developed a new material using CF fiber as reinforcement in epoxy resin, which possesses low dielectric constant, and hence can be useful /suited for electronic applications [**68-70**].

2.4 Erosion Wear Characteristics of Composites

Wear is damage to a solid surface usually involving progressive loss of materials, owing to relative motion between the surface and a contacting substance or substances. It is a material response to the external stimulus and can be mechanical or chemical in nature. The effect of wear on the reliability of industrial components is recognized widely and the cost of wear has also been recognized to be high. Systematic efforts in wear research were started in the 1960s in industrial countries. The direct costs of wear failures, i.e., wear part replacements, increased work and time, loss of productivity, as well as indirect losses of energy and the increased environmental burden, are real problems in everyday work and business. Although wear has been extensively studied scientifically, in the 21st century there are still wear problems present in industrial applications. This actually reveals the complexity of the wear phenomenon.

Erosion due to the impact of solid particles can either be constructive (material removal desirable) or destructive (material removal undesirable), and therefore, it can be desirable to either minimize or maximize erosion, depending on the application. Constructive applications include sand blasting, high-speed water-jet cutting, blast stripping of paint from aircraft and automobiles, blasting to remove the adhesive flash from bonded parts, erosive drilling of hard materials, and most recently, in the abrasive jet micromachining of silicon and glass substrates for optoelectronic applications, and the fabrication of components for micro-electromechanical system (MEMS) and micro-fluidic applications. Solid particle erosion is destructive in industrial applications such as erosion of machine parts, surface degradation of steam turbine blades, erosion of pipelines carrying slurries and particle erosion in fluidized bed combustion systems. In most erosion processes, target material removal typically occurs as the result of a large number of impacts of irregular angular particles, usually carried in pressurized fluid streams. The fundamental mechanisms of material removal, however, are more easily understood by analysis of the impact of single particles of a known geometry. Such fundamental studies can then be used to guide development of erosion theories involving particle streams, in which a surface is impacted repeatedly.

After developing primitive fiber reinforced composite (FRC) in 1940s, they have been widely used because of their superior specific strength and also high corrosion resistance. Initially FRC was composite reinforced with glass fibers (GFRC), however reinforcement of new fibers such as carbon/graphite and aramid have increased their importance recently. The development of these high-performance fibers, use of FRC into industrial applications such as load bearing parts of buildings, bridges, tank / vessels and transportations can be recognized [**71,72**]. To ensure the durability of FRCs for industrial applications, it is necessary to discuss the degradation behavior and mechanism under various conditions such as stress, corrosion and erosion etc. Several parts and equipments are exposed to erosive conditions, for example pipes for hydraulic or pneumatic transportation [**73-75**], nozzle and impeller for sand-blasting facility [**76**], internal surface of vessels used for fluidized bed or with catalysis [**77-79**] , nose of high-velocity vehicle [**80**], blades/propellers of planes and helicopters [**81**] etc., some of them made from fibrous composites. Polymer composites with both discontinuous and continuous fiber reinforcement possess usually very high specific (i.e. density related) stiffness and strength when measured in plane. Therefore, such composites are frequently used in engineering parts in automobile, aerospace, marine and energetic applications. Due to the operational requirements in dusty environments, the study of solid particle erosion characteristics of the polymeric composites is of high relevance.

Polymers are finding an ever increasing application as structural materials in various components and engineering systems. The high specific strength and stiffness of polymers are primarily responsible for their popularity. However, the resistance of polymers to solid particle erosion has been found to be very poor [**82**], and in fact it is two or three orders of magnitude lower than metallic materials [**83**]. One possible way to overcome such a shortcoming is to introduce a hard second phase in the polymer to form polymer matrix composites (PMCs). A number of investigators [**82-89**] have evaluated the resistance of various types of PMCs to solid particle erosion. Tilly **[83]** and Tilly and Sage **[85]** tested nylon and epoxy reinforced with various fibers such as graphite, glass and concluded that the reinforcement can either increase or decrease the erosion resistance depending on the type of fibers. Zahavi and Schmitt [**84**] tested a number of PMCs for erosion resistance and concluded that glass-reinforced epoxy composite had a particularly good erosion resistance. The above study was extended further by Tsiang [**86**]. He carried out sand erosion tests on a wide range of thermoset and thermoplastic PMCs having glass, graphite and Kevlar fibers in the forms of tape, fabric and chopped mat as reinforcements. Kevlar fibers in an epoxy resin provided the best erosion resistance. In a recent study, Mathias et al. [**87**] and also Karasek et al. **[89]** have evaluated the erosion behavior of a graphite fiber reinforced bismaleimide polymer composite. These investigators observed the erosion rates of the PMC to be higher than the unreinforced polymer. Many of the investigators [**83-87, 89**] also consistently noted that the erosion rates of the PMCs were considerably larger than those obtained in metallic materials. In addition, composites with a thermosetting matrix mostly exhibited a maximum erosion rate at normal impact angles (i.e. a brittle erosion response) while for the thermoplastic polymer composites the erosion rate reached a maximum at an intermediate impact angle in the range 40^0-50^0 signifying a semi ductile erosion response.

The wear behavior of composite materials has received much less attention than that of conventional materials. However, as composites are utilized to an increasing extent in the aerospace, transportation and process industries, their durability may become a prime consideration. In erosion, material is removed by an impinging stream of solid particles. Studies to develop an understanding of the mechanisms of erosive wear have been motivated by reduced lifetimes and failures of mechanical components used in erosive environments e.g. in pipelines carrying sand slurries, in petroleum refining [**90, 91**] and in aircraft gas turbine/compressor blades [**92**]. In addition to these studies, which were conducted to understand erosion behavior in isotropic materials, there is increasing interest in understanding the erosion behavior of anisotropic materials. Because of their very high specific stiffness and strength, composites are now used extensively in aircraft structures. The understanding of erosive wear behavior is obviously important for such structures e.g. helicopter rotor blades. While polymeric coatings have been developed to protect composite aircraft structures from rain erosion [**93, 94**] there is little understanding of the mechanisms of erosive wear in these materials. For polymers and composite materials, Tilly and Sage **[85]** investigated the influence of velocity, impact angle, particle size and weight of impacted erosion for nylon, carbon-fiber reinforced nylon, epoxy resin, polypropylene and glass-fiber-reinforced plastic. Their results showed that, for the particular materials and conditions of their tests, composite materials generally behaved in an ideally brittle fashion (i.e. maximum erosion rate occurred at normal impact). Fiber reinforcement may improve or worsen the resistance to erosion depending on the type of fibers used. In addition, the erosion rates in composites continued to increase with particle size in contrast with the independence of erosion rate on particle size found in steel with particle diameters greater than about 100 μm [**84, 89**].

Erosion experiments on metallic materials, ceramics and polymers have clearly indicated that the hardness of the eroding or abrading material by itself cannot adequately explain the observed behavior. As a result, combined parameters involving both hardness and fracture toughness have been utilized to correlate the erosion data of metals [**95-104**], ceramics [**99,100**] and polymers [**102**] In addition, correlation between the fatigue and the erosion or wear resistance has also been observed in the case of polymers [**103]**. Solid particle erosion is a dynamic process that leads to progressive loss of material from the target surface due to impingement of fast moving solid particles. This mode of wear is one of the important problems in various gas and liquid flow passages such as flow in pipes and pipe fittings (valves, bends, elbows, flow meters etc.), flow in pumps, turbines, compressors and many others. Erosion may cause equipment malfunctioning (vibration, leakage, excessive energy losses etc.) and may also lead to complete failure of machine components. Accurate prediction of the rate of erosion in a specific application is one of the very complicated problems since it requires detailed investigation of the solid particle motion before and after impact. The difficulty arises mainly from the fact that most flows occurring in industrial processes are turbulent which makes the particle trajectory and impact characteristics difficult to predict taking into consideration all fluid forces acting on the particle. Erosion tests have been performed under various experimental conditions (erodent flux conditions, erosive particle characteristics) on different target composites. It has been concluded that composite materials present a rather poor erosion resistance [**104-108**]. A crucial parameter for the design with composites is the fiber content as it controls the mechanical and thermo-mechanical responses. In order to obtain the favored material properties for a particular application, it is important to know how the material performance changes with the fiber content under given loading conditions. The erosive wear behavior of polymer composite systems as a function of fiber content has been studied successfully in the past [**109-111**]. It was concluded that the inclusion of brittle fibers in both thermosetting and thermoplastic matrices leads to compositions with lower erosion resistance. Nevertheless, no definite rule is available to describe how the fiber content affects the erosion rate of a composite.

Miyazaki and Hamao [**109**] have examined the effect of fiber inclusion on the erosion behavior by comparing the erosion rate of an FRC with that of a neat resin, which is the matrix material of the FRC. It was observed that the inclusion of brittle fibers in both thermosetting and thermoplastic matrices leads to compositions with lower erosion resistance. The results show the clear correlation between interfacial strength and erosion rate. Thus, the erosion behavior of polymeric materials depends first of all on their nature. Thermosetting polymers, such as epoxy (EP) show brittle erosion whereas the erosion response of thermoplastics is of ductile type [**108**]. The same categorization applies for the related composites. It was demonstrated that the maximum erosion rate is at an oblique impact angle of 30^0 and at 60^0–90^0 for polymers eroding in ductile and brittle manner respectively [**104,112-114**]. A schematic of erosion wear process is demonstrated in fig.2.2.

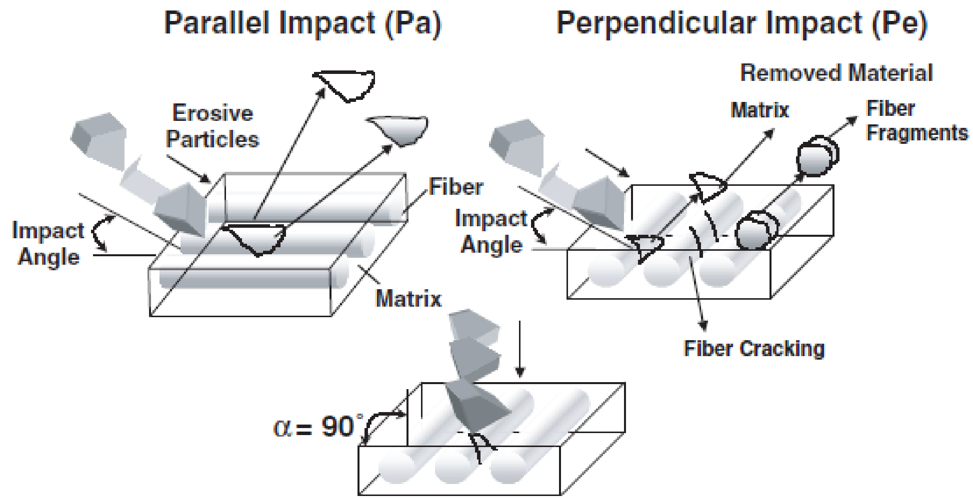


Fig.2.2. Schematic diagram of erosion mechanisms, at different angle of impact.

Rubbers, on the other hand, present a maximum erosion rate at 30^0, but the failure mechanisms differ from those of thermoplastic resins. It is, therefore, a great challenge to study the solid particle erosion of a system that may show both brittle and ductile erosion behavior depending on its composition and structural characteristics. Erosion of ductile materials by the impact of hard solid particles at low and moderate velocities (2-100 m/sec) can cause significant damage to structural components in many industrial applications. During impact on the elastic–plastic target, particle energy transfers into rebound and plastic deformation of the target [**115**]. Rebound of the particle is caused by the elastic energy stored in the particle and target material and the magnitude of this energy is determined by the ratio of the rebound to the initial particle velocity. This ratio, called the restitution coefficient, depends on the mechanical properties of the target material and erodent, and impact parameters (i.e. velocity, impact angle, and particle size). The extent of erosion damage is related to the ability of the material to elastically recover and therefore, it is important to understand the effect of target mechanical properties, such as hardness, on the restitution coefficient. Several studies have been conducted to measure the restitution coefficient of various target erodent systems [**115-117**]. However, these measurements are complicated and often inaccurate because of the difficulties involved in measuring rebound velocity of the particle. As already mentioned, solid particle erosion is a general term used to describe mechanical degradation wear of a solid material subjected to a stream of abrasive erodent particles impinging on its surface and the effects of solid particle erosion have been recognized for a long time [**118**]. Damage caused by erosion has been reported in several industries for a wide range of situations. Examples can be cited for rocket motor tail nozzles [**119**], helicopter rotors and gas turbine blades [**120**], parametric dependence of erosion wear for the parallel flow of solid–liquid mixtures [**121**], boiler tubes exposed to fly ash [**122**]. The existing models of solid particle erosion treat ductile and brittle materials as separate and distinct, generating two basic theories. These include subsurface lateral crack propagation in brittle materials [**123,124**], and micro machining or damage accumulation and fatigue impact in ductile materials [**125,126**]. Sheldon [**127**] noted the importance of the tangential velocity component of the impacting particle and concluded that erosion occurs by a combination of ductile and brittle modes.

In general, the erosive wear behavior of material depends on various operating parameters, such as velocity and angle of impact, particle size, shape, flux rate, etc. [**116**]. Literature on the effect of velocity of erodent on wear performance is sparse as compared to that on other parameters [**129-133**]. Earlier studies have shown that the value of the velocity exponent depends on the nature of both the target and the erodent. Tilly and Sage [**84**] reported a value of velocity exponent of 2.3 for 125–150 μm quartz erodent's impacting a range of materials from metals to plastics. They also reported that the velocity exponent decreased with decreasing size of the erodent. While studying the erosive wear behavior of glass eroded by 300 μm size iron spheres, Dhar and Gomes [**134,135**] postulated that there was a threshold velocity value below which deformation was elastic and hence no damage occurred. Tilly [**136**] proposed that the threshold velocity depended on the particle size of the erodent and obtained a value of 2.7 m/s for 225 μm quartz against 11% chromium steel. Scattergood and Routbort [**137**] found that the velocity exponent increased with decreasing particle size of the erodent. Arnold and Hutchings [**129**] found that the erosion rate of natural rubber and epoxidized natural rubber had very strong dependence on the impinging velocity above 70 m/s. Rao et al.[**138**] reviewed the effect of impact velocity on the erosive wear of various polymers and composites. The influence of impact angle and dose of the erodent on the erosive wear behavior of various poly-amides with different methylene to amide (CH_2 /CONH) ratio has also been reported [**139**]. Therefore, it is worthwhile to study the influence of various impact parameters like impinging angle, velocity, dose of the erodent etc. on the erosive wear behavior of composites. Available reports on the research work carried out on erosion can be classified under three categories; experimental investigations, erosion model developments and numerical simulations. Tilly [**136**] presented a thorough analysis of the various parameters affecting erosion, including particle properties, impact parameters, particle concentration, material temperature and tensile stress. He also reviewed the different mechanisms of erosion, which were categorized into brittle and ductile behaviors. Because of its direct relevance to gas and oil industries, erosion of pipes and pipe fittings attracted many researchers. Several experimental studies were conducted with the main objective being to determine the rate of erosion in such flow passages and its relation with the other parameters involved in the process. Among these studies are the works by Rochester and Brunton [**140**], True and Weiner [**141**], Glaeser and Dow [**142**], Roco et al. [**143**], Venkatesh [**144**], and Shook et al. [**145**]. Soderberg et al. [**146,147**] and Hutchings [**148,149**] reported the advantages and disadvantages of such experiments. The recent experimental study by McLaury et al. [**150**] on the rate of erosion inside elbows and straight pipes provided correlations between the penetration rate and the flow velocity at different values of the elbow diameter, sand rate and size. Edwards et al. [**151**] reported the effect of the bend angle on the normalized penetration rate.

The objective of most of these experimental studies was to provide data for establishing a relationship between the amount of erosion and the physical characteristics of the materials involved, as well as the particle velocity and angle of impact. Blanchard et al. [**152**] carried out an experimental study of erosion in an elbow by solid particles entrained in water. The elbow was examined in a closed test loop. Electroplating the elbow surface and photographing after an elapsed period of time were carried out to show the wear pattern.

2.5 Abrasive Wear of Polymer Composite

Abrasive wear occurs when a hard rough surface slides across a softer surface [**153**]. ASTM (American Society for Testing and Materials) define it as the loss of material due to hard particles or hard protuberances that are forced against and move along a solid surface [**154**]. Abrasive wear is commonly classified according to the type of contact and the contact environment [**155**]. The type of contact determines the mode of abrasive wear. The two modes of abrasive wear are known as two-body and three-body abrasive wear. Two-body wear occurs when the grits, or hard particles, are rigidly mounted or adhere to a surface, when they remove the material from the surface. The common analogy is that of material being removed with sand paper. Three-body wear occurs when the particles are not constrained, and are free to roll and slide down a surface. The contact environment determines whether the wear is classified as open or closed. An open contact environment occurs when the surfaces are sufficiently displaced to be independent of one another.

There are a number of factors which influence abrasive wear and hence the manner of material removal. Several different mechanisms have been proposed to describe the manner in which the material is remove. Three commonly identified mechanisms of abrasive wear are:

- Plowing
- Cutting
- Fragmentation

Plowing occurs when material is displaced to the side, away from the wear particles, resulting in the formation of grooves that do not involve direct material removal. The displaced material forms ridges adjacent to grooves, which may be removed by subsequent passage of abrasive particles. Cutting occurs when material is separated from the surface in the form of primary debris, or microchips, with little or no material displaced to the sides of the grooves. This mechanism closely resembles conventional machining. Fragmentation occurs when material is separated from a surface by a cutting process and the indenting abrasive causes localized fracture of the wear material. These cracks then freely propagate locally around the wear groove, resulting in additional material removal by spalling[**155**] Abrasive wear can be measured as loss of mass by the Taber Abrasion Test according to **ISO 9352 / ASTM D 1044**.

Reinforced polymers are used extensively in applications where resistance to adhesive and abrasive wear failure is important for materials section. Polymers form a special class of materials because of their self lubricity, which allows them to function without external convectional liquid lubrication. However polymers have some inherent tribological limitations, such as significantly low thermal conductivity, and diffusivity as compared with metals. Frictional heat generated at the sliding contacts cannot be dissipated properly, and hence, flash temperature at sliding contacts remains high. Their poor thermal stability also makes them more vulnerable due to loss of mechanical strength with an increase in the surface temperature. The thermal expansion coefficients of polymers are ten times greater than those of metals, posing problems related to dimensional clearances. In addition to the creeping tendency, polymers have low dimensional stability and rigidity. They have poor compressive strength (approximately 30 times less) compared with those of other classes of tribomaterials. These inherent limitations restrict the utility of polymers under severe operating conditions, such as high loads, speeds, and temperatures. Therefore, reinforcements (fibrous or particulate) generally are used to increase the load-carrying capacity strength, resistance to creep and wear. Limitations of strength and thermal conductivity can be overcome efficiently by the right selection of reinforcements and fillers in the appropriate amount, combination, and processing technology. The tribological performance of reinforced polymers is governed by the type of base matrix, the nature of the filer(type , amount, size, shape aspect ratio, distribution, orientation, combination with fillers and the quality of bonding with the matrix), and the operating conditions. Fibers are far more wear resistant than the matrix and hence control the wear of the composite

In recent years, there have been rapid growth in the developments and applications of fiber reinforced thermo-setting polymer composites such as epoxy, and polyester. This is due to the realization of their good strength, low density, and high performance/cost ratios with rapid clean processing. Polymer and their composites are finding ever increasing usage for numerous industrial applications such as bearing material, rollers, seals, gears, cams, wheels, clutches and transmission belts etc. [**156-158**]. Therefore, the mechanical and tribological behavior of these materials should be studied systematically. Among wear types, abrasive wear situation encountered in vanes and gears, in pumps handling industrial fluids, sewage and abrasive-contaminated water, roll neck bearings in steel mills subjected to heat, shock loading; chute liners abraded by coke, coal and mineral ores; bushes and seals in agricultural and mining equipment, have been received increasing attention [**159**].

Polymers and their composites form a very important class of tribo-engineering materials and are invariably used in mechanical components, where wear performance in non-lubricated condition is a key parameter for the material selection [**160,161**]. Carbon, graphite, glass and aramid fabrics are the most commonly used fabrics for fiber reinforced polymer composites especially for making tribo-components and aircraft structures that encounter harsh operating conditions such as high stresses, speeds, temperatures, etc. [**162-164**]. Amongst these fabrics, carbon fabric (CF), not only offers maximum extent of strength and wear resistance enhancement but also boost the thermal conductivity that is crucial from a tribo-point of view. The rapid dissipation of frictional heat produced at the asperity contacts protects the matrix from degradation and fibers from delamination and helps in the retention of all performance properties. Moreover, in general, carbon fibers help in imparting additional lubricity because of layer-lattice structure of graphite [**165**]. The bi-directional fabric reinforcement offers a unique solution to the ever increasing demands on the advanced materials in terms of better performance and ease in processing [**166**]. A notable advance in the polymer industries has been the use of fiber and particulate fillers as reinforcement in polymer matrix [**167**]. However, the matrix materials also play an important role as is the case for thermoset resin matrix composites which can be designed for specific applications by properly selecting the polymer.

In design there are two main characteristics which make polymer and reinforced polymer attractive compared to conventional metallic materials. These are relatively low density value and reliable tailoring capability to provide the required strength and stiffness.

One of the main important characteristics of materials is wear and friction. Wear is defined [**168**] as the damage to a solid surface, generally involving progressive loss of material, due to relative motion between that surface and contacting substance or substances. The five types of wear are abrasive, adhesive, erosion, fatigue and fretting. Abrasive wear has a contribution of at least 60% of the total cost due to wear **[169].**

Several researchers have reported on the abrasive wear behavior of fiber reinforced polymer composites [**170-172**]. It is important to note that the fiber reinforcement (short, long, and continuous) in polymer increases the wear resistance and reduces coefficient of friction in the case of sliding wear. It does not automatically mean that these materials will perform better when sliding under abrasive wear situations, but often the opposite trend results. The influence of fiber and/or fillers on the abrasive wear performance of polymer is a more complex and unpredictable phenomenon [**173**]. Chand et al. [**174**] studied low stress abrasive wear behavior of short E-glass fiber reinforced polymer composites with and without fillers by using rubber wheel abrasion test apparatus. They reported that higher weight fraction of glass fibers (45%) in the composites improves the wear resistance as compared to the composite containing less glass fibers (40%). Evans et al. [**175**] studied the abrasion wear behavior for 18 polymers and they noticed that low density polyethylene (LDPE) showed the lowest wear rate in abrasion against rough mild steel, but a higher wear rate in abrasion with coarse corundum paper. Budinski [**176**] investigated the abrasion resistance of plastics and concluded that the abrasion resistance of plastics is inconclusive and recommended for further study. Cenna et. al.[**177**] studied abrasion resistance of three types of vinyl ester resin systems, i.e., un-reinforced, reinforced with glass fibers, and reinforced with particles of ultra-high molecular weight polyethylene (UHMWPE). They found that UHMWPE reinforced composites showed enhanced wear resistance against both coal and mineral ignimbrite used as abrasives. Cirino et al. [**178, 179**] investigated the sliding and abrasive wear behavior of poly-ether-ether-ketone (PEEK) with different continuous fiber types and reported that the wear rate decreases with increase in the fiber content and also studied the mechanisms of abrasive wear using scanning electron microscopy and discussed the topic by schematic illustrations of basic wear phenomena. The abrasive wear behavior of short carbon/glass fiber reinforced with PEEK/polyphenylene sulfide (PPS) thermoplastic polymers was reported by Lhymn et al. [**180**] and they concluded that the wear rate is sensitive to the fiber orientation axis with respect to the sliding direction. The normal oriented specimen showed a lower wear rate than the anti-parallel or parallel specimen. Friedrich [**181**] has reported that the wear rate of thermoplastics is not improved by adding short fibers if the wear mechanism is highly abrasive in nature. In contrast, in the case of continuous fiber reinforcement, an increased wear resistance has been reported.

Mainly, work has been reported on the sliding-wear behaviour of fibre-reinforced polymer composites. Bijwe et al. [**182**] have investigated a polyetherimide short glass-fibre-reinforced composite for sliding wear against a mild steel counterface and have concluded that the results may be compared with the performance of commercially available bearing materials. Researchers [**183-186**] have also reported friction and wear of some advanced composites. The main emphasis has been given to the friction and wear of unidirectional, continuous, fibre-reinforced polymer composites. Most of them concluded that the wear of the material is not an intrinsic property but rather depends on the volume fraction, as well as the type and direction of orientation with respect to the sliding direction. Tsukizoe and Ohmae [**187**] derived an empirical wear equation for advanced composites and finally concluded that wear of composites proceeded by wear thinning of the reinforcement. Subsequently, fibre breaking and peeling-off of the fibres occurs. Bahadur and Zheng [**188**] found that the sliding wear rate is a function of the fibre weight fraction, for short fibre-reinforced polyester composites. Tewari and Bijwe [**189**] in their paper on the abrasive wear of polyimide and particulate filled composites, observed that load and particle size are important parameters that effect the wear characteristics. Chand and Fahim [**190**] used polyester and epoxy resins reinforced with glass fibres in woven form for abrasive wear studies and derived a theoretical model for the specific wear rate of their composites. Lhymn et al. [**191**] reported, for short fibre-reinforced polyester composites, that the wear rate is sensitive to the orientation of the fibre axis with respect to the sliding direction, that a ploughing mechanism is evident and that the corelation between the wear factor and the friction coefficient is not clear. The limited literature on the abrasive wear limits the level of understanding for two-body abrasive wear.

2.6 Wear Modeling

The correlations between wear resistance and characteristic properties of polymers have been discussed in terms of various semi-empirical equations by some pioneers. These include, e.g. the Ratner–Lancaster equation [**192,193**], i.e. the relationship of the single pass abrasion rate with the reciprocal of the product of ultimate tensile stress and strain or an equation used by Friedrich [**194**] to correlate the erosive wear rate of polymers with the quotient of their hardness to fracture energy. Although these equations are quite helpful to estimate the wear behavior of polymers in some special cases, wear normally is very complicated and it therefore depends on many more mechanical and other parameters. This means that simple functions cannot always cover all the prevailing mechanisms under wear. For predictive purposes, an artificial neural network (ANN) approach has, therefore, been introduced recently into the field of wear of polymers and composites by Velten et al. [**195**] and Zhang et al. [**196**]. An ANN is a computational system that simulates the microstructure (neurons) of biological nervous system. The most basic components of ANN are modeled after the structure of the brain. Inspired by these biological neurons, ANN is composed of simple elements operating in parallel. ANN is the simple clustering of the primitive artificial neurons. This clustering occurs by creating layers, which are then connected to one another. How these layers connect may also vary. Basically, all ANN have a similar structure of topology. Some of the neurons interface the real world to receive its input, and other neurons provide the real world with the network's output. All the rest of the neurons are hidden from view. As in nature, the network function is determined largely by the interconnections between neurons, which are not simple connections, but some non-linear functions. Each input to a neuron has a weight factor of the function that determines the strength of the interconnection and thus the contribution of that interconnection to the following neurons. ANN can be trained to perform a particular function by adjusting the values of these weight factors between the neurons, either from the information of outside the network or by the neurons themselves in response to the input. This is the key to the ability of ANN to achieve learning and memory. The multi-layered neural network is the most widely applied neural network, which has been utilized in the most of the research works for materials science reviewed by Zhang and Friedrich [**197**]. Back propagation algorithm can be used to train these multi-layer feed-forward networks with differentiable transfer functions to perform function approximation, pattern association and pattern classification. The term back propagation refers to the process by which derivatives of network error, with respect to network weights and biases, can be computed. The training of an ANN by back propagation involves three stages: (a) the feed-forward of the input training pattern, (b) the calculation and back propagation of the associated error and (c) the adjustment of the weights. This process can be used with a number of different optimization strategies.

Wear processes in composites are complex phenomena involving a number of operating variables and it is essential to understand how the wear characteristics of the composites are affected by different operating conditions. Although a large number of researchers have reported on properties, performance and on wear characteristics of composites, neither the optimization of wear processes nor the influence of process parameters on wear rate has adequately been studied yet. Selecting the correct operating conditions is always a major concern as traditional experiment design would require many experimental runs to achieve satisfactory result. In any process, the desired testing parameters are either determined based on experience or by use of a handbook. It, however, does not provide optimal testing parameters for a particular situation. Thus, several mathematical models based on statistical regression techniques have been constructed to select the proper testing conditions [**198-203**]. The number of runs required for full factorial design increases geometrically, whereas fractional factorial design is efficient and significantly reduces the time. This method is popular because of its simplicity, but this very simplicity has led to unreliable results and inadequate conclusions. The fractional design might not contain the best design point. Moreover, the traditional multi-factorial experimental design is the “change-one-factor-at-a-time” method. Under this method only one factor is varied, while all the other factors are kept fixed at a specific set of conditions. To overcome these problems, Taguchi and Konishi [**204**], advocated the use of orthogonal arrays and Taguchi [**205**], devised a new experiment design that applied signal-to-noise ratio with orthogonal arrays to the robust design of products and processes. In this procedure, the effect of a factor is measured by average results and therefore, the experimental results can be reproducible. Phadke [**206**], Wu and Moore [**207**] and others

[**208-211**] have subsequently applied the Taguchi method to design the products and process parameters. This inexpensive and easy to operate experimental strategy based on Taguchi's parameter design has been adopted to study effect of various parameters and their interactions in a number of engineering processes.

The literature survey presented above inspired to carry out the present piece of research work.

Chapter 3

Materials and Methods

Chapter 3
MATERIALS AND METHODS

This chapter describes the materials and methods used for the processing of all the composites under this investigation. It presents the details of the characterization and wear tests which the composite samples are subjected to. The methodology related to the design of experiment technique based on Taguchi and artificial neural network method is also presented in this part of the thesis.

3.1 Matrix material

Epoxy LY 556, chemically belonging to the 'epoxide' family is used as the matrix material. Its common name is Bisphenol A Diglycidyl Ether. The hardener with IUPAC name NN0-bis (2-aminoethylethane-1,2-diamin) used with the epoxy has the designation HY-951. The epoxy resin and the hardener were supplied by Ciba Geigy India Ltd. Resin and hardeners are mixed in a ratio of 10:1 by weight as recommended. Density of the epoxy resin system is 1.1 g/cc.

3.2 Composite fabrication

The chicken feathers are cleaned with a polar solvent, like ethanol and dried. The quills were removed and short fibers (5-10 mm length, having aspect ratio ≥ 3000) are selected. The feathers are mixed with the epoxy by stirring at room temperature and disc-shaped samples (of 12mm diameter and 2.5 mm thickness) are prepared by uniaxial pressing at 1.00 ton load. Four samples of epoxy resin, Sample "A" (pure epoxy resin), sample "B" (epoxy + 10% chicken feather fiber), Sample "C" (epoxy + 20% chicken feather fiber) and sample "D" (epoxy+ 30% chicken feather fiber), are prepared under the same conditions of temperature and pressure. The fabricated samples/slabs are shown in Fig.3.1.

Designation	Composition
EC_1	Epoxy + 10 wt% Poultry Feather
EC_1	Epoxy + 20 wt% Poultry Feather
EC_1	Epoxy + 30 wt% Poultry Feather

Table 3.1 Designation and detailed composition of the composites

Fig.3.1. shows different feather fiber reinforced epoxy composites

3.3 Physical and Mechanical Characterization

3.3.1 Hardness measurement

Hardness measurement is done using a Leitz micro-hardness tester. A diamond indenter, in the form of a right pyramid with a square base and an angle 136^0 between opposite faces, is forced into the material under a load F. The two diagonals X and Y of the indentation left on the surface of the material after removal of the load are measured and their arithmetic mean L is calculated. In the present study, the load considered F= 24.54N and Vickers hardness number is calculated using the following equation

$$\mathbf{Hv = 0.1889 \frac{F}{L^2}} \qquad \mathbf{(1)}$$

$$\mathbf{L = \frac{X+Y}{2}}$$

where F is the applied load (N), L is the diagonal of square impression (mm), X is the horizontal length (mm), and Y is the vertical length (mm).

3.3.2 Density and void fraction

The theoretical density of composite materials in terms of weight fraction can easily be obtained as for the following equations given by Agarwal and Broutman [212].

$$\rho_{ct} = \frac{1}{\frac{Wf}{\rho f}+\frac{Wm}{\rho f}} \qquad \mathbf{(2)}$$

Where, W and ρ represent the weight fraction and density respectively. The suffix f, m and ct stand for the fiber, matrix and the composite materials respectively. The actual density (ρ_{ce}) of the composite, however, can be determined experimentally by simple water immersion technique. The volume fraction of voids (V v) in the composites is calculated using the following equation:

$$V_V = \frac{\rho ct - \rho ce}{\rho ct} \qquad \mathbf{(3)}$$

3.3.3 Flexural strength

The short beam shear (SBS) tests are performed on the composite samples at room temperature to evaluate the value of flexural strength (FS). It is a 3-point bend test, which generally promotes failure by inter-laminar shear. The SBS test is conducted as per **ASTM D2344-84**, using the Instron -1195 UTM. Span length of 40 mm and the cross head speed of 1 mm/min are maintained. The flexural strength (*F.S.*) of any composite specimen is determined using the following equation. A typical flexural test is shown in Fig.3.2.

$$F.S = \frac{3PL}{2bt^2} \qquad \textbf{(4)}$$

Where, *L* is the span length of the sample. P is the load applied; b and t are the width and thickness of the specimen respectively.

Fig.3.2. Loading arrangement for the specimens.

3.3.4 FTIR Spectroscopy

Fourier Transform Infrared (FTIR) spectroscopy is an important analysis technique which detects various characteristic functional groups in molecules of any matter [**213**]. On interaction of an infrared light with the matter, chemical bonds will stretch, contract and bend and as a result, each chemical functional group tends to absorb infrared radiation in a specific wavelength range regardless of the structure of the rest of the molecule. Based on this principle, functional groups present in composite materials are identified. It is performed in a FTIR spectrophotometer interfaced with IR microscope operated in reflectance mode. The microscope is equipped with a video camera, a liquid nitrogen-cooled mercury cadmium telluride (MCT) detector and a computer controlled translation stage, programmable in the x and y directions. The spectra are collected in the 400 cm-1to 4000 cm-1region with 8 cm-1 resolution, 60 scans and beam spot size of 10µm-100µm. The FTIR imaging in the present investigation is carried out using a Perkin Elmer Spectrum RX (1).

3.3.5 Dielectric Properties

The samples of dimension 12mm in diameter and 2.5 mm in thickness are coated with graphite paint on the opposite faces and heated for 15 min (at 100^0C) in oven for drying. Dielectric measurements are carried out at frequency of 1Hz to 1 MHz using HP-4192A LF Impedance Analyzer, connected with a data acquisition system. The temperature is controlled with a programmable oven. All the datas are collected at an interval of 5^OC, while heating at a rate of 5^OC/min at a frequency of 100Hz is maintained. In dielectric analysis, each sample is placed between two gold electrodes (parallel plate sensors, TA instruments). The dielectric constant of composite are measured according to **ASTM D5023**.

3.3.6 Scanning Electron Microscopy

The surfaces of the raw chicken feather fiber and the composites are examined with scanning electron microscope JEOL JSM-6480LV. The fibers are washed, cleaned thoroughly, air-dried and are coated with 100 Å thick platinum in JEOL sputter ion coater and observed SEM at 20 kV. Similarly the composite samples are mounted on stubs with silver paste. To enhance the conductivity of the samples, a thin film of platinum is vacuum-evaporated onto them before the photomicrographs are taken.

3.3.7 Erosion test apparatus

The set up used in this study for the solid particle erosion wear test is capable of creating reproducible erosive situations for assessing erosion wear resistance of the prepared composite samples. It consists of an air compressor, an air particle mixing chamber and accelerating chamber. The schematic diagram of the erosion test rig is shown in Figure 3.3. Dry compressed air is mixed with the erodent particles which are fed at constant rate from a sand flow control knob through the nozzle tube and then accelerated by passing the mixture through a convergent brass nozzle of 3mm internal diameter. These particles impact the specimen which can be held at different angles with respect to the direction of erodent flow using a swivel and an adjustable sample clip. Square samples of size 40mm×40mm are cut from the plaques for erosion tests. The velocity of the eroding particles is determined using standard double disc method [214]. In the present study, dry silica sand (spherical) of different particle sizes (200µm, 400 µm and 600 µm) are used as erodent. A standard test procedure is employed for each erosion test. The samples are weighed to an accuracy of ± 0.1 mg using an electronic balance, eroded in test rig for 5 min. and then weighed again to determine the weight loss. The ratio of weight loss to the weight of the eroding particles causing loss (i.e. testing time ×particle feed rate) is then computed as the dimensionless incremental erosion rate. This procedure repeated till the erosion rate attains a constant steady-state value.

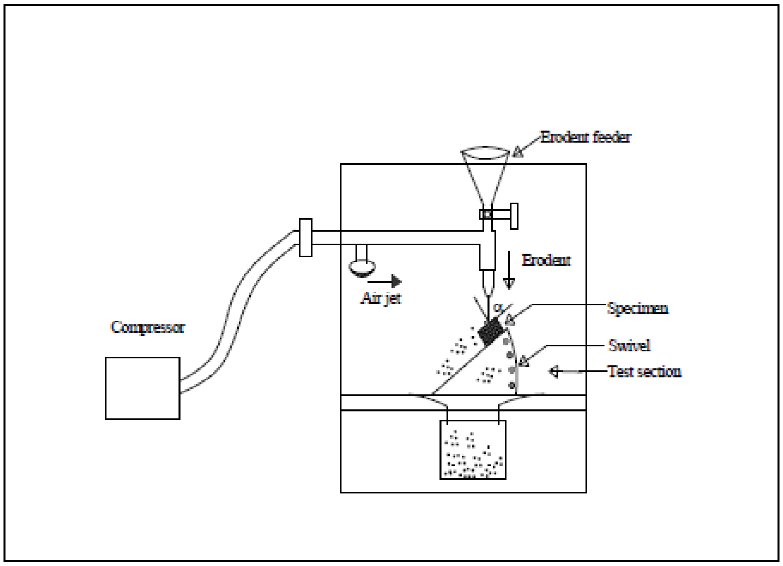


Fig.3.3. schematic diagram of the erosion test rig

3.3.8 Abrasive Test Apparatus

To evaluate the performance of these composites under dry sliding condition, abrasive wear tests are carried out in a pin-on-disc type friction and wear monitoring test rig (supplied by DUCOM) as per ASTM G 99, the schematic is shown in Fig.3.4. The polymer composite specimen (of size 8mm diameter and 15mm long) were abraded against the waterproof SiC papers (i.e 220µm, 320µm and 420µm grit size), fixed on the rotating disc. The specimen is held stationary and the disc is rotated while a normal force is applied through a lever mechanism. A series of tests are conducted with three sliding velocities of 0.429, 0.628 and 0.719 cm/s under three different normal loadings of 5, 10 and 15 N. The material loss from the composite surface is measured using a precision electronic balance with accuracy ±0.1mg and the specific wear rate (mm^3/ N-m) is then expressed on 'volume loss' basis as:

$$W_S = \frac{\Delta m}{\rho\ t\ Vs\ Fn} \qquad \textbf{(5)}$$

Where **Δm** is the mass loss (in gm.) during the test duration, **ρ** is the density of the composite (gm/mm^3), **t** is the test duration (sec), **Vs** is the sliding velocity (m/sec), and **Fn** is the average normal load (Newton). The specific wear rate is defined as the volume loss of the specimen per unit sliding distance per unit applied normal load.

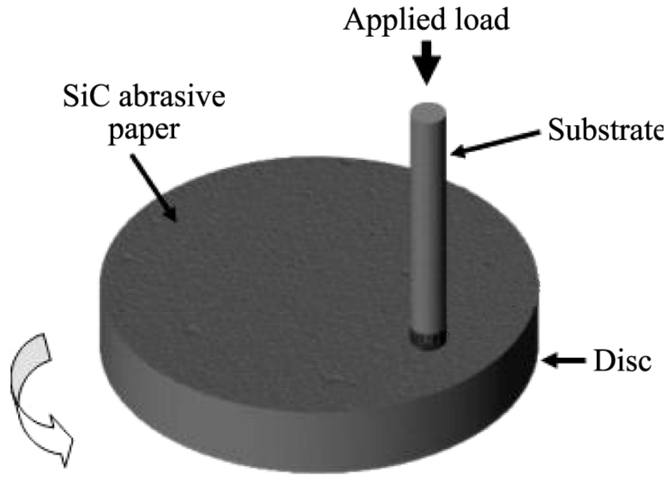


Fig.3.4. Schematic diagram of pin on disc set up.

3.4 Process optimization and Taguchi method

Statistical methods are commonly used to improve the quality of a product or process. Such methods enable the user to define and study the effect of every single condition possible in an experiment where numerous factors are involved. Solid particle erosion is such a process in which a number of control factors collectively determine the performance output i.e. the erosion rate. Hence, in the present work a statistical technique called Taguchi method is used to optimize the process parameters leading to minimum erosion of the polymer composites under study. This part of the chapter presents the Taguchi experimental design methodology in detail.

3.4.1 Taguchi Experimental Design

Every single discipline has researchers carrying out experiments to observe and understand a certain process or to discover the interaction and effect of different variables. From a scientific viewpoint, these experiments are either one or a series of tests to either confirm a hypothesis or to understand a process in further detail. Experiments from a manufacturing point of view, however, are concerned with finding the optimum product and process, which is both cost effective and of a high quality. In order to achieve a meaningful end result, several experiments are usually carried out. The experimenter needs to know the factors involved, the range these factors are varied between, the levels assigned to each factor as well as a method to calculate and quantify the response of each factor. This one factor at a time approach will provide the most favorable level for each factor but not the optimum combination of all the interacting factors involved. Thus, experimentation in this scenario can be considered as an iterative process. Although it will provide a result, such methods are not time or cost effective. But the design of experiments is a scientific approach to effectively plan and perform experiments, using statistics. In such designs, the combination of each factor at every level is studied to determine the combination that would yield the best result. The advantage of such design schemes is that it will always determine the effect of factors on the result. Design of experiment is a powerful analysis tool for modeling and analyzing the influence of control factors on performance output. The most important stage in the design of experiment lies in the selection of the control factors.

3.4.2 Neural Computation

Wear is considered as a non-linear problem with respect to its variables: either materials or operating conditions. To obtain minimum wear rate, combinations of operating parameters have to be planned. Therefore a robust methodology is needed to study these interrelated effects. In this work, a statistical method, responding to the constraints, is implemented to correlate the operating parameters. This methodology is based on artificial neural networks (ANN), which is a technique that involves database training to predict input-output evolutions. The details of this methodology are described by Haykin [**215**]. Each of these parameters is characterized by one neuron and consequently the input layer in the ANN structure has five neurons. The database is built considering experiments at the limit ranges of each parameter. Experimental result sets are used to train the ANN in order to understand the input-output correlations. The database is then divided into three categories, namely: (i) a training category, which is exclusively used to adjust the network weights and (ii) a test category, which corresponds to the set that validates the results of the training protocol. Usually seventy five percent data (patterns) is used for training and twenty five percent for testing. The input variables are normalized so as to lie in the same range group of 0-1. The output layer of the network has only one neuron to represent wear rate. Different ANN structures (Input-Hidden-Output nodes) with varying number of neurons in the hidden layer are tested at constant cycles, learning rate, error tolerance, momentum parameter, noise factor and slope parameter. The number of cycles selected during training is high enough so that the ANN models could be rigorously trained. The C++ coding used for neural computing developed by Haykin [215] using back propagation algorithm is used as the prediction tool for erosion wear rate of different composites under various test conditions. The three-layer neural network having an input layer (I) with four input nodes, a hidden layer (H) with twelve neurons and an output layer (O) with one output node employed for this work. A typical three layer network condition is shown in Fig.3.5.

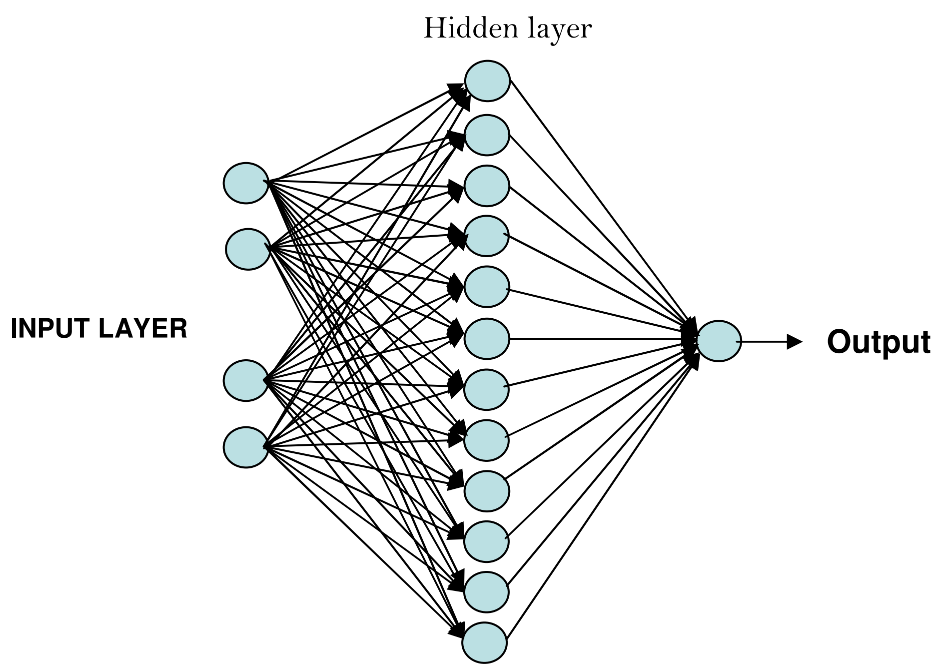


Fig.3.5. The three layer neural network.

Chapter summary

This chapter has provided:

- The descriptions of materials used in the experiments.
- The details of fabrication and characterization of the composites.
- The description of erosion and abrasive wear test.
- An explanation of the Taguchi experimental design and neural computation.

The next chapter presents the physical and mechanical properties of the polymer composites under study.

Chapter 4

RESULTS AND DISCUSSION

Chapter 4

RESULTS AND DISCUSSION

4.1 PHYSICO - MECHANICAL PROPERTIES OF COMPOSITES

4.1.1 Introduction

Novel bio-based composite material that is suitable for electronic, automotive, and aeronautical applications can be developed from polymer matrix resin using chicken feather fiber as reinforcement. The feather fiber, when removed from the quill, is used as the reinforcement in composites in its natural state. This environmental friendly, low-cost composite can be a suitable for developing polymer composites. These fibres mainly constitute keratin, are hollow, light, and tough material which is compatible to polymer resins viz. epoxy resin. The incorporation of keratin fibers in the polymer resin enhanced the physical and mechanical properties. The use of chicken feather fibers in composites as reinforcing fibers offers an environmentally benign solution for feather disposal, and also presents to poultry producers the option of reducing waste disposal costs and gaining a profit from feather waste.

4.1.2 Morphology of Chicken Feather

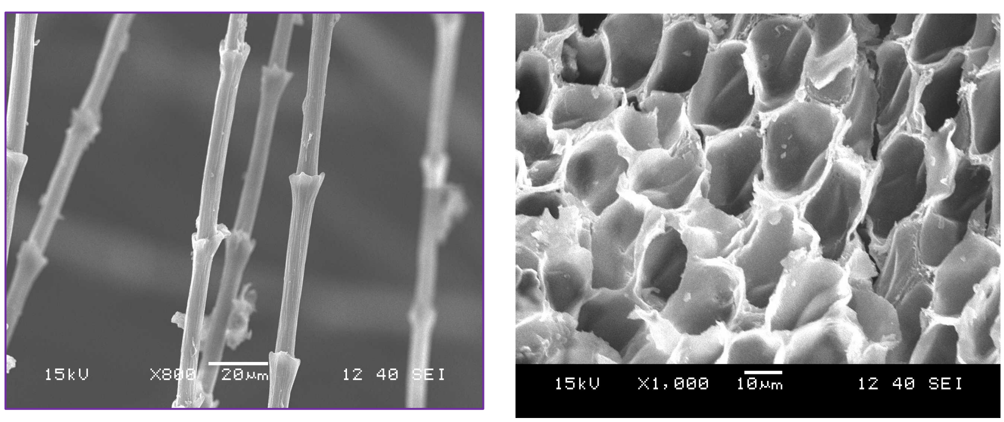


Fig.4.1.SEM analysis of chicken feather fiber and its hollow structure,
(a) feather strand and (b) cross section view of the strand

The chicken feather fibers are light and hollow in structure as reveals from figure 4.1. It is evidenced from the figure that, the nodes and hooks in the feather bears hollow structure which contains a significant volume of air, can impart low density as well as with good dielectric behavior.

4.1.3 Density

The density of chicken feather is about 0.80 g/cm^3, and that of epoxy resin is about 1.125gm/cm^3. The density of the new materials decreases with an increase of chicken feather content as shown in table 4.1 for chicken feather reinforced epoxy matrix composite. This is due to presence of air in hollow structure in chicken feather fiber (barbicels) as shown in fig.4.1.

sample	Density Theoretical (gm/cm^3)	Density Experimental (gm/cm^3)	Void Fraction (%)
Epoxy	1.125	1.123	0.17
Epoxy+10% Chicken Feather	1.072	1.023	0.45
Epoxy+20% Chicken Feather	1.027	1.014	0.12
Epoxy+30% Chicken Feather	1.017	1.009	0.07

Table 4.1. Variation of density and Void fraction (%) with different wt% of chicken feather, reinforced in epoxy matrix.

The theoretical and experimentally measured densities of all chicken feather reinforced composite samples along with the corresponding volume fraction of voids are presented in Table 4.1 It may be noted that the composite density values calculated theoretically from weight fractions (using eqn.-2, Ch.3), are not in agreement with the experimentally determined values. The difference is a measure of voids / pores present in the composites. It is clear from Table 4.1 that, with addition of short chicken feather fibers the volume fraction of voids is not much increased. Density of a composite depends on the relative proportion of matrix and reinforcing materials and this is one of the most important factors determining the properties of the composites. The void content is the cause for the difference between the values of true density and the theoretically calculated one. The voids significantly affect some of the mechanical properties and even the performance of composites in the place of use. The knowledge of void content is desirable for estimation of the quality of the composites. It is understandable that a good composite should have less voids. However, presence of void is unavoidable in composite making particularly through hand-lay-up route. The composites under the present investigation possess very less voids. It has been reported that, the higher volume fraction of lower density natural fibers in polymer composites also reduces the weight of the final component [**216**].

4.1.4 FTIR Analysis

Chicken feather contain ~91% protein (keratin), ~1% lipids and ~8% water. The structure of keratin, the major constituent of chicken feather affects the chemical durability. Because of extensive cross linking and strong covalent bonding within it structure, keratin shows good durability and resistance to degradation. The amino acids sequence of chicken feather is very similar to that of other feather. The sequence is largely composed of cystien, glycine, proleine and serin. Carboxylic acid, amino, alcoholic, amid and disulphide's are main functional groups present in chicken feather. Fourier transform infrared (FTIR) spectroscopy analysis is a major tool to determine the interaction between fibers and matrix material [**217**]. The results obtained in our investigation are as below:

Functional Groups Present	I.R Peaks
N-H stretching H -bonding	3285 cm^{-1}
C-N stretching in amide groups	1644 cm^{-1}
N-H bending vibration	1537 cm^{-1}
C-S stretching vibration	718 cm^{-1}

Table.4.2. FTIR peaks of different functional groups present in chicken feather.

The functional groups present in chicken feather and epoxy are tabulated in table 4.2 & 4.3 respectively. The FTIR peaks of the epoxy and the composite with 30% CF are compared with in Fig 4.2.

Functional Groups Present	I.R Peaks
C-O-C stretching vibration in epoxy	1245 Cm^{-1}
C-O-C stretching vibration in benzo-eather	1033 Cm^{-1}
O-H stretching vibration in free alcohol	3420 Cm^{-1}
C-H stretching vibration in benzene	3000-3030 Cm^{-1}
C-H stretching vibration in methyl group	2927 Cm^{-1}

Table.4.3 shows FTIR peaks of different functional groups present in pure epoxy.

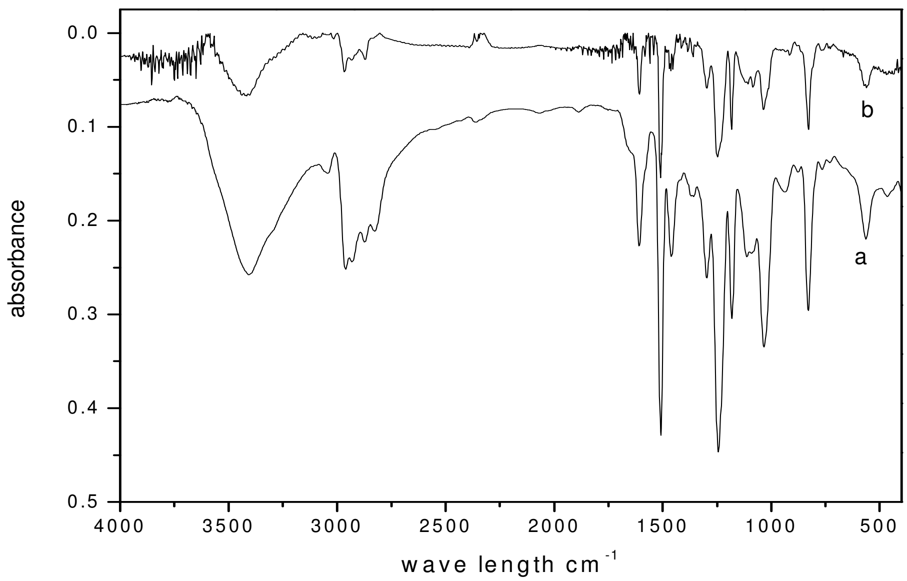


Fig.4.2. FTIR peaks of (a) pure epoxy resin and (b) epoxy + (30wt %) chicken feather.

In epoxy raw chicken feather composite, the surface of the chicken feathers come in contact with epoxy matrix .The oxygen atom of epoxy form H- bonding with hydrogen atom which is attached with nitrogen atom of polypeptide chain i.e. keratin present in chicken feather. More the number of hydrogen bonding between the two surfaces, more is the strength of that matrix composite. The FTIR study of the epoxy chicken feather composite shows some evidence about the formation of hydrogen bonding. The peak range about 3500cm^{-1} to 3200 cm^{-1} become more wide and short in case of chicken feather composite as compared to corresponding peaks in epoxy resin . Due to the formation of hydrogen bonding between oxygen atom of epoxy and hydrogen atom of polypeptide chain, there is stretching of bonds in epoxy matrix. Hence the bond length of all bonds attached to oxygen atom increases slightly; therefore bonds become week and absorb I.R in slightly low frequency region.

4.1.5 Dielectric Constant

Figure 4.3 shows the k-values of the new composite materials developed from CF fibers and epoxy resin. The k-values decrease from 4.5 to 2.1, with an increase in CF content. Hence, the new CF composite has a lower dielectric constant than some conventional semiconductor insulators, epoxies, poly imides, and other dielectric materials. A decrease of k-value of the insulator increases the operating speed. The delay time of the electronic signal is proportional to the square root of k, and values close to k=1 are most desirable. The measured k-value of the CF itself was 1.7, may be because CF fibers contain a significant volume of air. The ideal minimum k-value is 1.0, as represented by air and therefore, a porous or high-air content material may have dielectric constants in the ultra-low-k (<2.2) region.

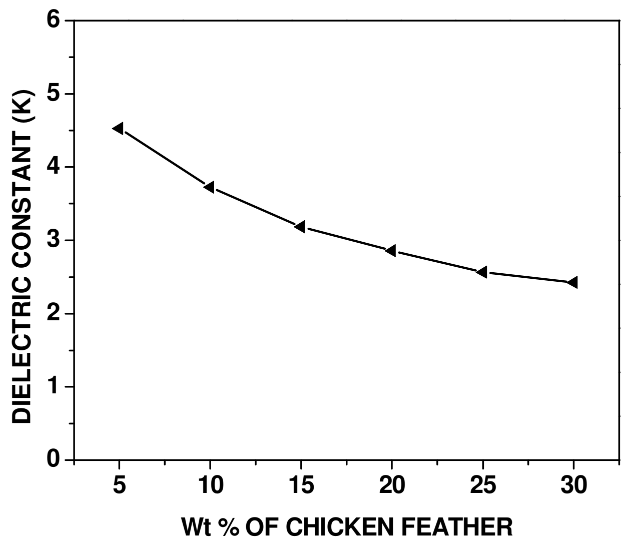


Fig.4.3. Dielectric constants of chicken feather epoxy composites at 25^0C.

The variation of the dielectric constant k with frequency is shown in Figure 4.4. At room temperature, a marked difference in dielectric constant k is found between epoxy resin and the composites prepared with different weight percentages of feather additions. An important observation is that, k decreases considerably with the addition of CF in epoxy resin, which most likely can be explained due to the CF having a lower dielectric constant k than the base epoxy resin, thus resulting in lowering the dielectric constant of these composites. The decrease of k with increasing frequency is the expected behavior in most dielectric materials, which is due to dielectric relaxation and is the cause of anomalous dispersion. From a structural point of view, the dielectric relaxation involves the orientation polarization, which, in turn, depends upon the molecular arrangement of the dielectric material. So, at higher frequencies the rotational motion of the polar molecules of dielectric is not sufficiently rapid for the attainment of equilibrium with the applied field, hence dielectric constant seems to decrease with increasing frequency.

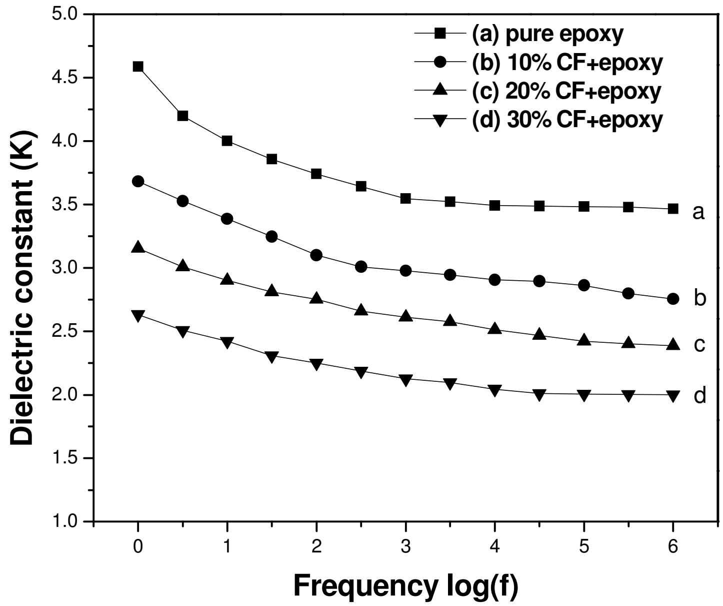


Fig.4.4. Frequency dependence of dielectric constant at room temperature.

The temperature dependence of the dielectric constant of CF composites is shown in Figure 4.5. The dielectric constant of the composite increased slightly with increasing temperature, may be resulting from the alignment of the dipoles when the composite get softened with temperature.

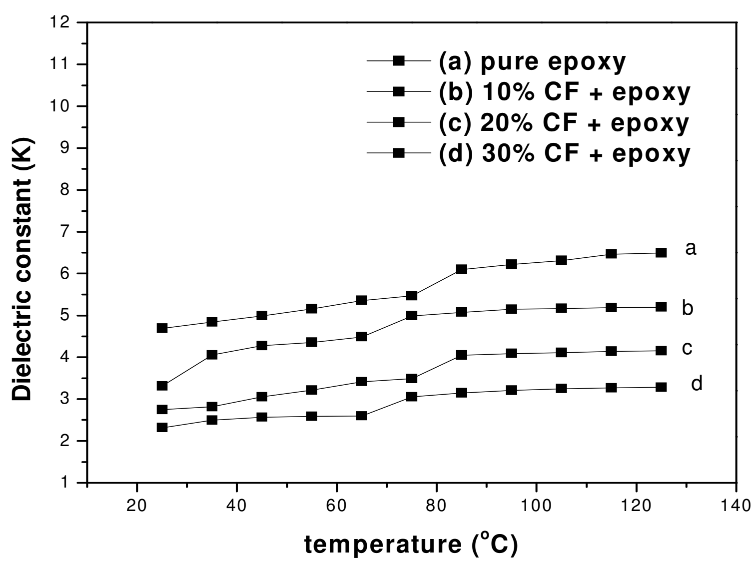


Fig.4.5. Frequency dependence of dielectric constant at different temperatures.

In dielectric tests, the measured value is separated into dielectric constant and dielectric loss factor. The dependence of the loss factor upon CF content is shown in Figure 4.6. Loss factor represents the energy required to align the dipoles and movement of ions. In our study it is observed that the loss factor decreases with increasing CF content, which appears to be a beneficial dielectric behavior.

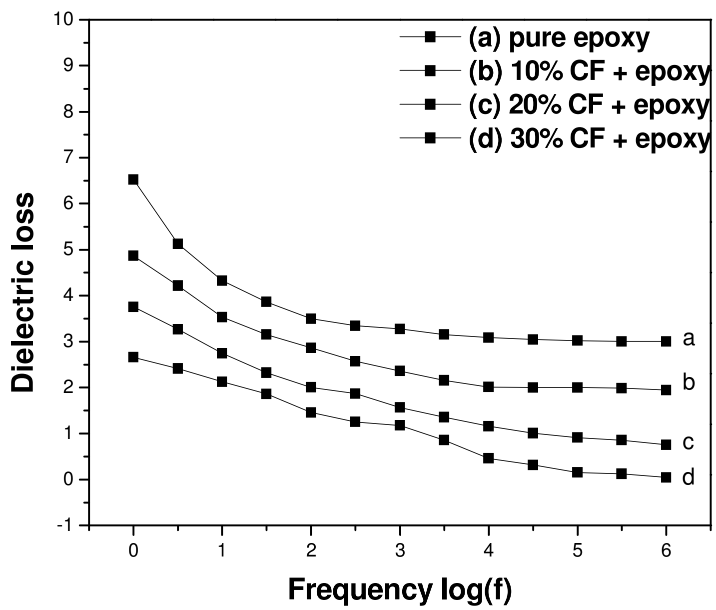


Figure.4.6. Frequency dependence of dielectric loss at room temperatures.

The thermal conductivity, thermal expansion, and dielectric properties of some polymer composites are systematically studied as a function of fiber volume fraction [218]. Their observation on variation of dielectric constant with other factors viz. reinforce vol. fraction and temperature etc. is at par with our observations.

4.1.6 Hardness

Fig.4.7 represents the hardness values of all different weight percentage of chicken feather reinforced composites. It can be visualized that, up to a certain limit (i.e. up to 20 wt.% of CF), hardness increases and then after the hardness of the composite does not increase much, with further increase in volume fraction of feather fiber additions. The low or marginal effect of these short fiber fillers on composite hardness may be due to the presence of pores and voids in the feather.

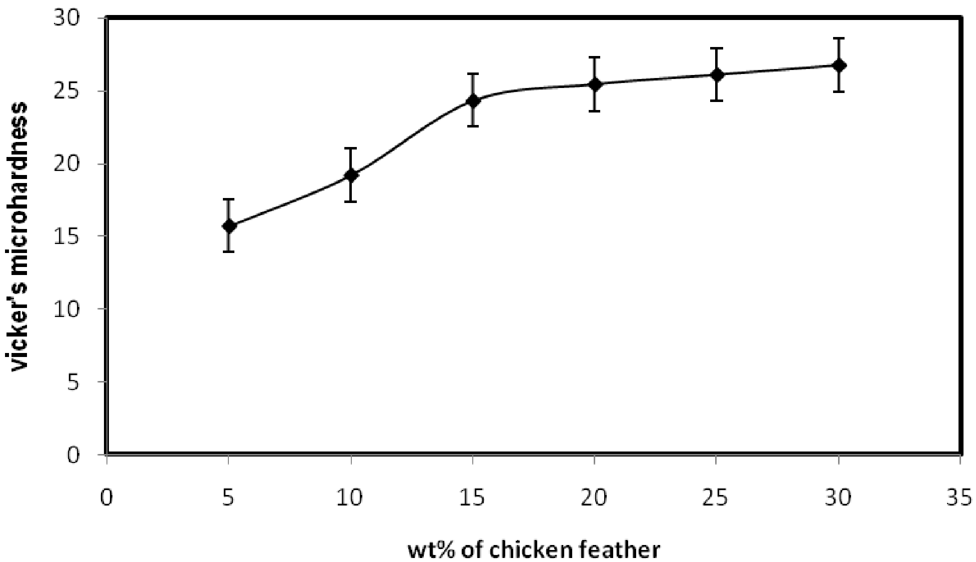


Fig.4.7. Variation of hardness of composites with wt% of chicken feather fiber reinforced epoxy composites.

4.1.7 Flexural Strength

Fig.4.8 shows the comparison of flexural strengths of the feather reinforced epoxy composites. There is an increase flexural strength with increase in wt% of short fiber chicken feather in composites, may be due to presence of nodes and hooks on the feather fibers (shown in SEM fig.4.1). which helped in increasing the interface bonding and thereby improve the structural properties of the composite. The micro-mechanical events that occur for a long fiber reinforced composite are not the same as those observed for a short fiber reinforced composites. In a short feather fiber, there are variations in stress distribution along the fiber matrix interface, and end effects can be neglected in the case of long fibers, but they can be very important in the case of short feather fiber reinforced composites.

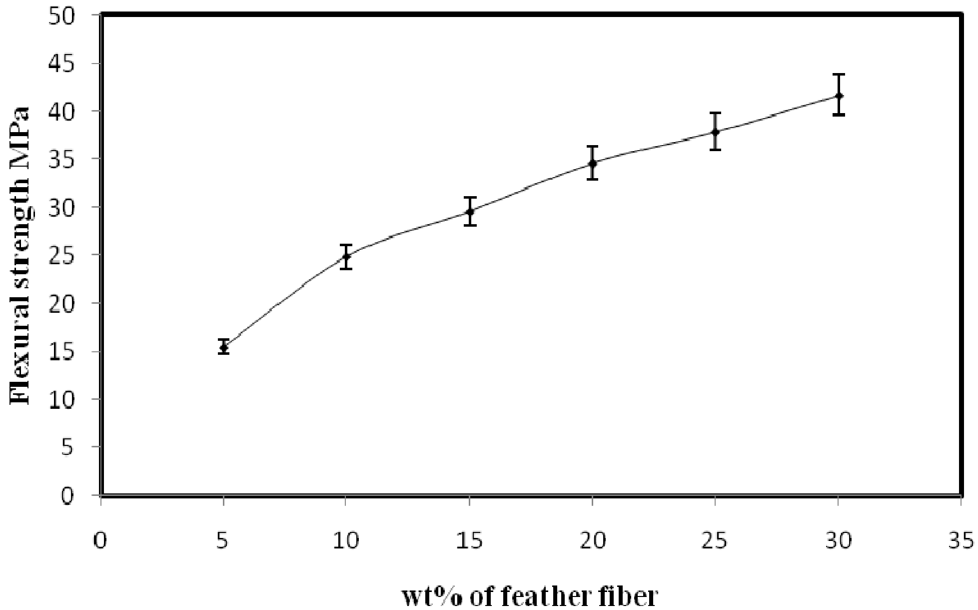


Fig.4.8. Variation of flexural strength of composites with wt% of chicken feather fiber reinforced epoxy composites.

Similar type of behavior is also been observed in other natural fiber reinforced composites. It has been reported that, hardness of kapok–polyester composites is decreased considerably by the incorporation of sisal fibers. The flexural properties were found to increase by incorporation of increased fabric content. Further, in kapok/sisal composites, addition of sisal fiber does not show any improvement in these properties. Sisal/polyester composites have lower hardness and flexural properties than the matrix and kapok/polyester composites [219].

From Scanning electron micrographs (SEM) of the fracture surfaces of the chicken feather composite (Figure 4.9), it is clear that the keratin fibers were broken without complete pullout during the fracture process, which indicates that adhesion between resin and feather fibers is quite good.

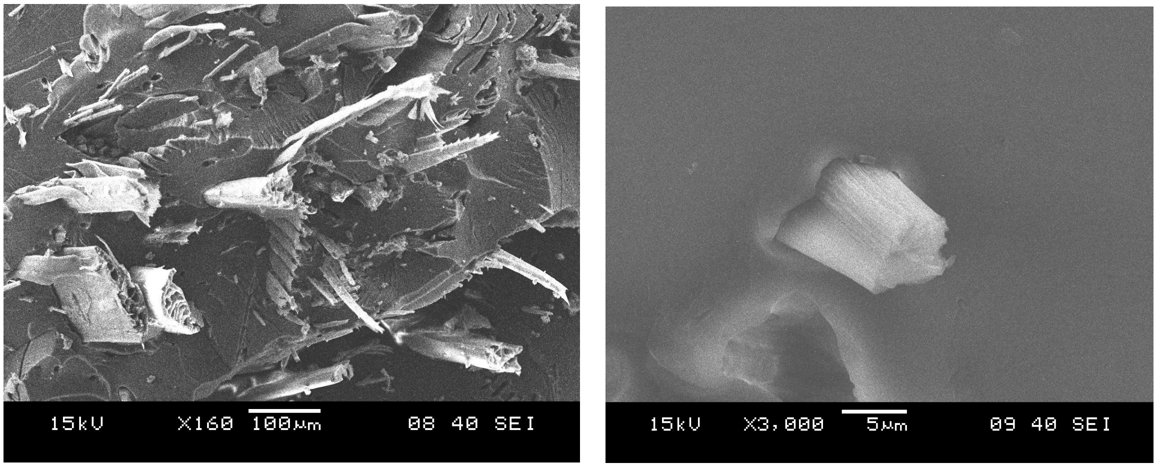


Fig.4.9. SEM micrographs of the fracture surface of chicken feather composites.

The mechanical properties of composites depend on the properties of the matrix and the fiber and on the interface bond strength, among other factors. The addition of keratin fibers improves the mechanical properties of the composites. This result is gratifying because the introduction of such natural fibers with high-air content and potential defects could have resulted in a considerably weaker material. The improvement in properties can be attested by using hybrid mats of feather.

4.2 STUDY OF EROSION WEAR BEHAVIOR

4.2.1. Introduction

In the present investigation proposed a theoretical model for erosion wear of short feather fiber reinforced epoxy composites. The test results of erosion trials carried out on the different wt % of feather fiber (i.e. neat polyester resin, 20 wt% and 30 wt % feather fibers) reinforced in epoxy matrix. The results of Taguchi technique and the implementation of artificial neural networks (ANN) analysis and prediction are also studied. The morphology of the worn surface of epoxy composites are also studied by SEM.

4.2.2 Erosion wear Test

An exhaustive review of the literature on erosion behavior of polymer composites reveals that parameters such as impact velocity, impingement angle, erodent size and filler content etc largely influence the erosion rate of polymer composites. The impact of these four parameters are studied with L_9 (3^4) orthogonal design, using Taguchi analysis. The control factors (parameters) and their selected levels considered for this investigation are given in Table 4.4. The tests are conducted at room temperature as per experimental design given in Table 4.5. In conventional full factorial experiment design, it would require 3^4 = 81 test runs to study inter-relationship/impact of four parameters each at three levels whereas, Taguchi's factorial experiment approach reduces it to only 9 test runs, offering a great advantage in terms of experimental time and cost. The experimental observations are further transformed into signal-to-noise (S/N) ratios. There are several S/N ratios available depending on the type of performance characteristics. The S/N ratio for minimum erosion rate can be expressed as "lower is better" characteristic, which is calculated as logarithmic transformation of loss function as shown below.

Smaller is the better characteristic $\frac{S}{N}$ = (-) 10 log $\frac{1}{n}\sum_{y} 2$

Where 'n' is the number of observations, and y the observed data. The plan of the experiments is as follows: the first column is assigned to erodent size (A), the second column to filler content (B), third column to impingement angle (C) and the fourth column to impact velocity (D) respectively are presented in table 4.4.

4.2.3 Application of Taguchi Analysis Technique

For any material, erosion wear depends on number of factors such as erodent size, feather fiber content, angle and sliding velocity etc, but which one is more prominent factor can found out performing minimum number of experiments using Taguchi analysis. Taguchi L_9 design having four factors and three levels i.e. erodent size (200 µm, 400 µm, 600 µm), filler content (0%, 20% CF, 30% CF), Impingement angle (30^0, 60^0,90^0) and impact velocity (32 cm/sec, 44 cm/sec, 58 cm/sec) respectively are shown in table 4.4.

Symbols	**Control Factors**	Levels I	II	III	Units
Factor A	Erodent size	200	400	600	µm
Factor B	Filler content	0	20	30	wt%
Factor C	Angle	30^0	60^0	90^0	degree
Factor D	Impact velocity	32	44	58	cm/sec

Table 4.4 Control factors and their selected levels considered in erosion wear test

Based on the above experimental conditions, the erosion wear rates obtained are presented in Table 4.5; in which the last column represents S/N ratio of the erosion rate which is in fact the average of two replications. The analysis was made using the popular software specifically used for design of experiment applications known as MINITAB 14.

Erodent size (µm)	Filler content (wt %)	Impingement angle (degree)	Impact Velocity (m/sec)	Erosion rate (mg/kg)	S/N ratios
200	0	30^0	32	98.231	-39.8450
200	20	60^0	44	96.458	-39.6868
200	30	90^0	58	99.425	-39.9499
400	0	60^0	58	178.787	-45.0467
400	20	90^0	32	119.543	-41.5505
400	30	30^0	44	70.632	-36.9800
600	0	90^0	44	185.663	-45.3745
600	20	30^0	58	101.752	-40.1509
600	30	60^0	32	81.156	-38.1864

Table .4.5 Specific wear rates obtained for different test conditions.

Level	A	B	C	D
1	-39.83	-43.42	-38.99	-39.86
2	-41.19	-40.46	4-0.97	-40.68
3	-41.24	-38.37	-42.29	-41.72
Delta	1.41	5.05	3.30	1.86
Rank	4	1	2	3

Table.4.6 Signal to noise ratio response table for erosion rate

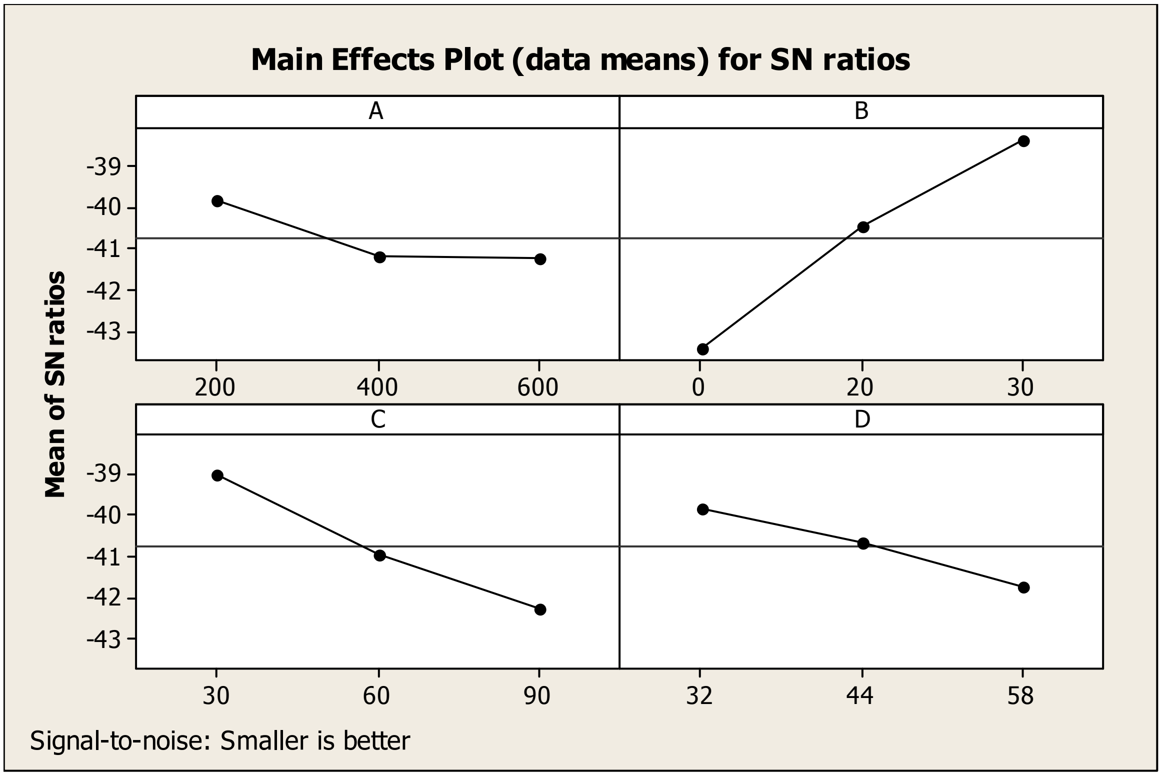


Fig.4.10. Effect of control factors on erosion rate

Analysis of the result leads to the conclusion that factor combination of A1, B3, C1 and D1 gives minimum erosion rate as shown in fig 4.10. From table 4.6, it is found that as far as the minimization of erosion rate is concerned; factors B, C and D, have significant effect on erosion of the composites whereas factor A has the least or negligible effect. From this response table, it can be concluded that among all the factors, feather fiber content (i.e. factor B) is most significant control factor followed by impingement angle and impact velocity.

The effect of erodent size and impact angle on erosion wear of all composites and neat epoxy (i.e. the matrix material) is evaluated in detail and the results are presented in fig 4.11 - fig.4.15.

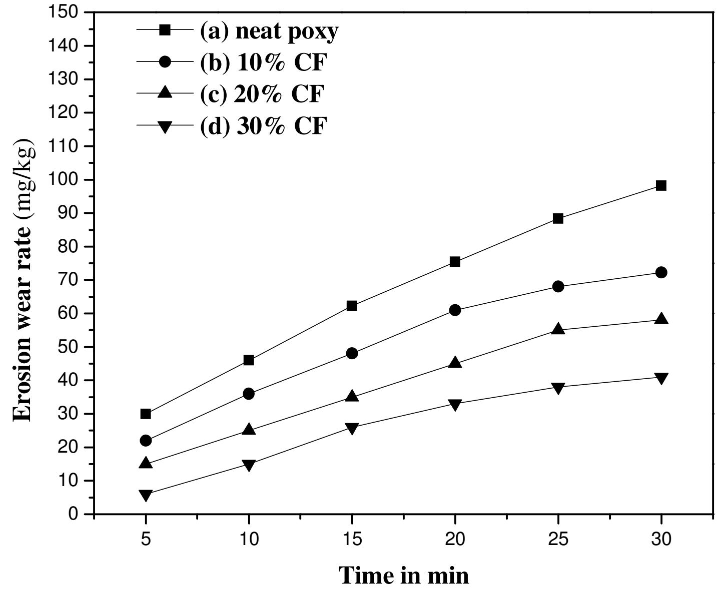


Fig.4.11. Erosion wear rate of feather fiber reinforced epoxy composite (erodent size 200μm, angle 30^0 ,impact velocity 44cm/sec)

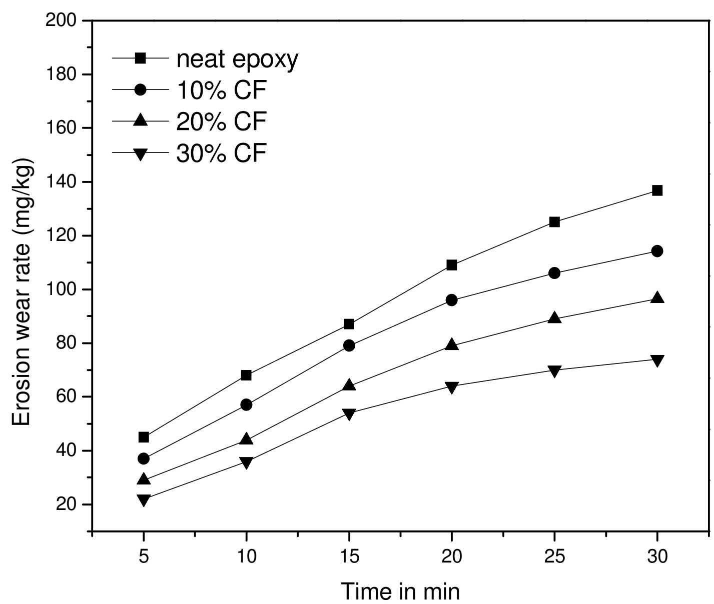


Fig .4.12. Erosion wear rate of feather fiber reinforced epoxy composite (erodent size 200μm, angle 60^0 ,impact velocity 44cm/sec)

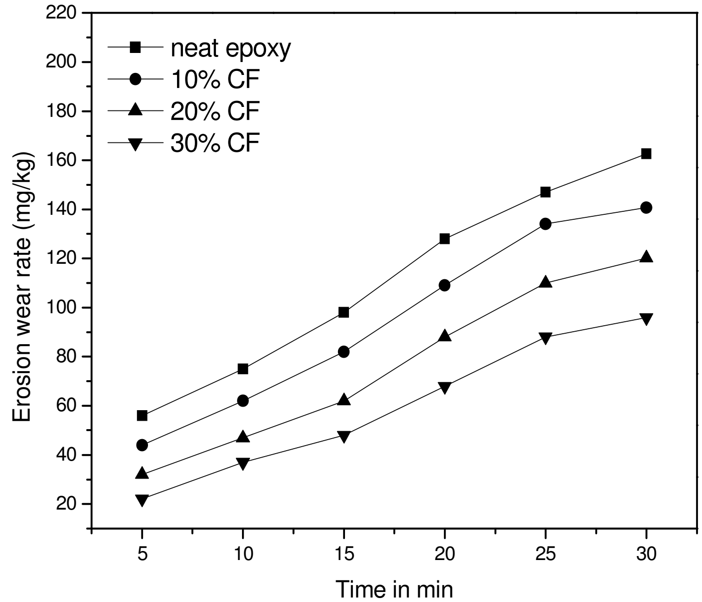


Fig .4.13. Erosion wear rate of feather fiber reinforced epoxy composite (erodent size 200µm, angle 90^0 ,impact velocity 44cm/sec)

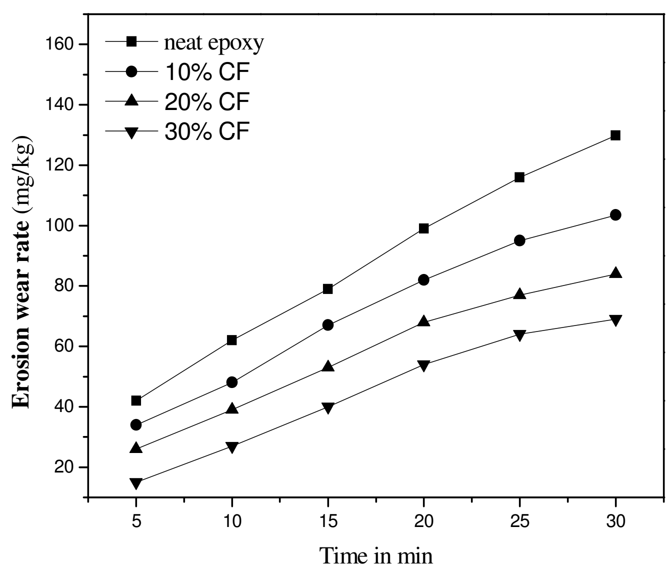


Fig.4.14. Erosion wear rate of feather fiber reinforced epoxy composite (erodent size 400µm, angle 90^0 ,impact velocity 44cm/sec)

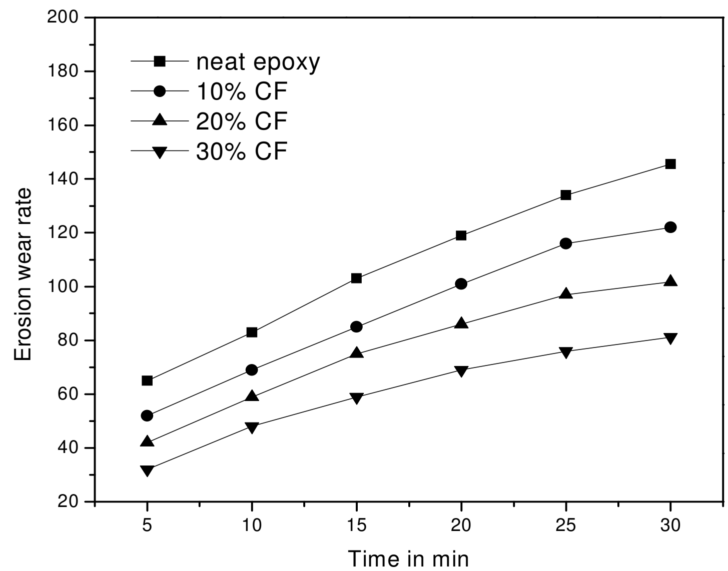


Fig.4.15. Erosion wear rate of feather fiber reinforced epoxy composite (erodent size 600μm, angle 90^0 ,impact velocity 44cm/sec)

Going through fig.4.11 to 4.15 it can be said that, the wear rate decreases with increasing the reinforcement content and attains a steady state after about 25 minutes of exposure to erodent. The erosion rate is slightly affected by erodent size, i.e. erosion rate is little higher with smaller particle size.

4.2.4 Artificial Neural Network analysis

In the present analysis, the erodent size, fiber content, impingement angle and impact velocity are taken as the four input parameters and erosion rate is the only output parameter. As already described, each of these parameters is characterized by one neuron and consequently the input layer in the ANN structure having four neurons. The database is built considering experiments at the limit ranges of each parameter. Experimental result sets are used to train the ANN in order to understand the input-output correlations. The database is then divided into three categories, namely:

(i) A validation category, which is required to define the ANN architecture and adjust the number of neurons for each layer.

(ii) A training category, which is exclusively used to adjust the network weights and

(iii) A test category, which corresponds to the set that validates the results of the training protocol.

The input variables are normalized so as to lie in the same range group of 0-1. To train the neural network used for this work, about 35 data sets at different test conditions are taken. It is ensured that these extensive data sets represent all possible input variations within the experimental domain. Thus, about seventy five percent of this data is used for training whereas twenty five percent data is used for testing while implementing the ANN protocol. So a network that is trained with this data is expected to be capable of simulating the erosion process. Different ANN structures (Input–Hidden layer–Output) with varying number of neurons in the hidden layer are tested at constant cycles, learning rate, error tolerance, momentum parameter and noise factor and slope parameter.

Input Parameters for Training	**Values**
Error tolerance	0.001
Learning rate (ß)	0.01
Momentum parameter(α)	0.1
Noise factor (NF)	0.5
Number of epochs	1,00,000
Slope parameter (£)	0.4
Number of hidden layer neuron (H)	12
Number of input layer neuron (I)	4
Number of output layer neuron (O)	1

Table.4.7. Input parameters selected for training.

Expt. No.	Erosion Wear Rate (Experimental) (mg/kg)	Erosion Wear Rate (ANN Predicted) (mg/kg)	Error (%)
1	98.231	92.459	1.838
2	96.458	92.159	0.304
3	99.425	105.725	2.719
4	178.787	184.856	0.578
5	119.543	125.415	1.576
6	70.632	64.902	2.129
7	185.663	192.719	1.125
8	101.752	107.452	1.565
9	81.156	72.357	1.722

Table.4.8. Comparison of experimental results with ANN predicted values.

Based on least error criterion, one structure, shown in Table 4.7, is selected for training of the input-output data. The learning rate is varied in the range of 0.001-0.1 during the training of the input-output data. The network optimization process (training and testing) is conducted for 1, 00,000 cycles for which stabilization of the error is obtained. Here the hidden layer number is 1 and neuron numbers in the hidden layer is varied and in the optimized structure of the network, this number is 12. The number of cycles selected during training is high enough so that the ANN models could be rigorously trained. Table 4.8 presents a comparison between the experimental and the ANN predicted results along with the error percentages.

The present study demonstrates the application of ANN for prediction of erosion wear rate beyond the experimental range in a complex process. It is observed that the error in ANN prediction lies in the range of 0-3 % which can further be reduced if the number of test patterns is increased.

Fig 4.16 and 4.17 show the erosion wear rate of the father fiber reinforced epoxy matrix composites obtained through ANN. This observation implies that the erosion rate decreases with increase in wt% of feather fiber and erosion rate increases with increase in impact angle. From fig 4.17 it appears that, the composites exhibit mixed mode type facture process, irrespective of impingment angle and amount of reinforcement.

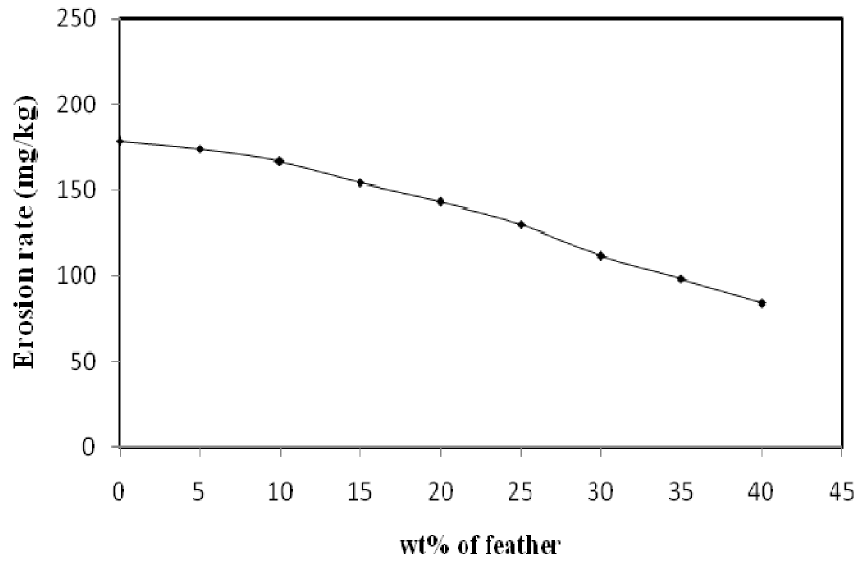


Fig.4.16. ANN predication on erosion wear of different wt % of feather fiber reinforced epoxy composite.

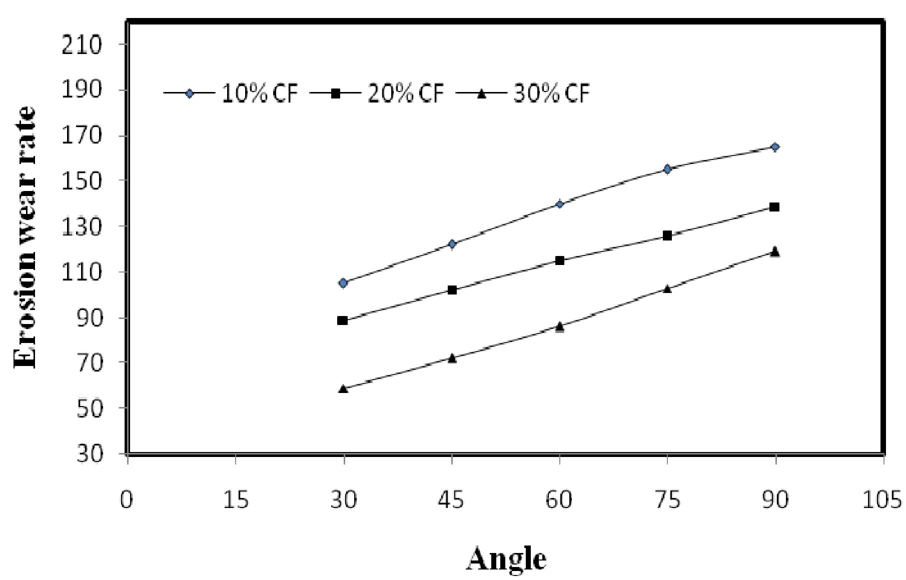


Fig. 4.17. ANN predication on erosion wear of feather fiber reinforced epoxy composite at different angle.

4.2.5 Surface Morphology

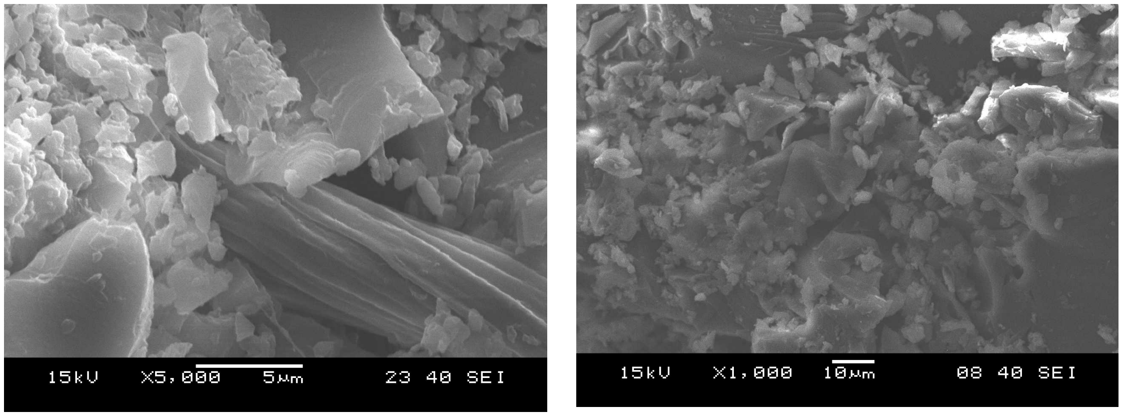


Fig. 4.18 SEM Micrograph of eroded feather reinforced epoxy composite.

The typical surface morphology of the worn surface is shown in Figure 4.18. The SEM micrographs of the eroded surfaces reveal that the matrix covering the fiber is chipped off due to repeated impact of (hard silica sand) particles. A crater thus formed and shows an array of (exposed), almost intact and unbroken and un-delaminated feather fibers. After the local removal of matrix this array of fibers is exposed to erosive environment. Small indentations on the epoxy matrix layer are also seen. The adhesion between the fibers and the epoxy matrix resists the wear due to erosion and the material loss therefore is reduced. The erodent particles strike the composite surface with maximum kinetic energy and consequently the material loss is high. The broken fibers are mixed with the matrix micro-flake debris in continuous exposure/erosion time which might also be a factor for attains a steady state i.e. reduction in wear rate.

Similar type of findings are also been made by Barkoula & Karger in case of some polymer composites also (220).

4.3 STUDY OF ABRASION WEAR BEHAVIOR

4.3.1 Introduction

In the present investigation proposed a theoretical model for abrasive wear of short feather fiber reinforced epoxy composites. The test results of erosion trials carried out on the different wt % of feather fiber (i.e. neat polyester resin, 20 wt% and 30 wt % feather fibers) reinforced in epoxy matrix. The results of Taguchi technique and the implementation of artificial neural networks (ANN) analysis and prediction are also studied. The morphology of the worn surface of epoxy composites are also studied by SEM.

4.3.2 Abrasive wear Test

Design of experiment is a powerful analysis tool for modeling and analyzing the influence of control factors on performance output. The most important stage in the design of experiment lies in the selection of the control factors. Therefore, a number of factors are included so that non-significant variables can be identified at the earliest opportunity. The wear tests are carried out under operating conditions given in Table 4.9. Four parameters, viz., abrasive paper grit size, short feather fiber content, applied load and sliding velocity each at three levels, are considered in this study in accordance with L_9 (3^4) orthogonal array as per design of experiments. Each of the experimental observations is transformed into a signal-to-noise (S/N) ratio. There are several S/N ratios available depending on the type of characteristics. The S/N ratio for minimum wear rate coming under smaller-is-better characteristic, which can be calculated as logarithmic transformation of the loss function.

Smaller is the better characteristic $\frac{S}{N} = -10 \log \frac{1}{n} \sum_y 2$

Where 'n' is the number of observations, and y the observed data. The plan of the experiments is as follows: the first column is assigned to abrasive paper grit size (A), the second column to short feather fiber content (B), third column to applied normal load (C) and the fourth column to sliding velocity (D).

4.3.3 Application of Taguchi Technique

Like erosion wear, abrasive wear depends on number of factors such as abrasive grit size, reinforcement content, applied load and sliding velocity etc. But which one is more prominent factor can be studied by using Taguchi analysis.

Symbols	Control Factors	Level I	II	III	Units
Factor A	Abrasive grit size	220	320	420	µm
Factor B	Filler content (chicken feather)	0	20	30	N
Factor C	Applied load	5	10	15	wt%
Factor D	Sliding velocity	0.419	0.628	0.718	cm/sec

Table.4.9. Control factors and their selected levels considered in abrasive wear test

The specific wear rates obtained based on above factors (table 4.9) are presented in Table 4.10 in which the last column represents S/N ratio of the erosion rate which is in fact the average of two replications; the response table for signal-to-noise ratios is given in table 4.11. The analysis is made using the popular software specifically used for design of experiment applications known as MINITAB 14.

Abrasive paper size (µm)	Filler content (wt %)	Load (N)	Sliding velocity (cm/sec)	Specific Wear Rate (mm^3/N-m)	S/N ratios
220	0	5	0.419	8.225	-18.3027
220	20	10	0.628	5.753	-15.1979
220	30	15	0.718	4.723	-13.4844
320	0	10	0.718	8.758	-18.8481
320	20	15	0.419	2.254	-7.0591
320	30	5	0.628	2.291	-7.2005
420	0	15	0.928	6.258	-15.9287
420	20	5	0.718	2.759	-8.8150
420	30	10	0.419	1.058	-0.489

Table.4.10. Test conditions with output results using L_9 orthogonal array.

Level	A	B	C	D
1	-16.2959	-18.5897	-8.5227	-1.2847
2	-9.2295	-5.8526	-5.1924	-12.5041
3	0.0967	-0.9864	-11.7135	-11.6398
Delta	16.3926	17.6033	6.5210	11.2194
Rank	2	1	4	3

Table .4.11. Response table for signal-to-noise ratios (Smaller is better).

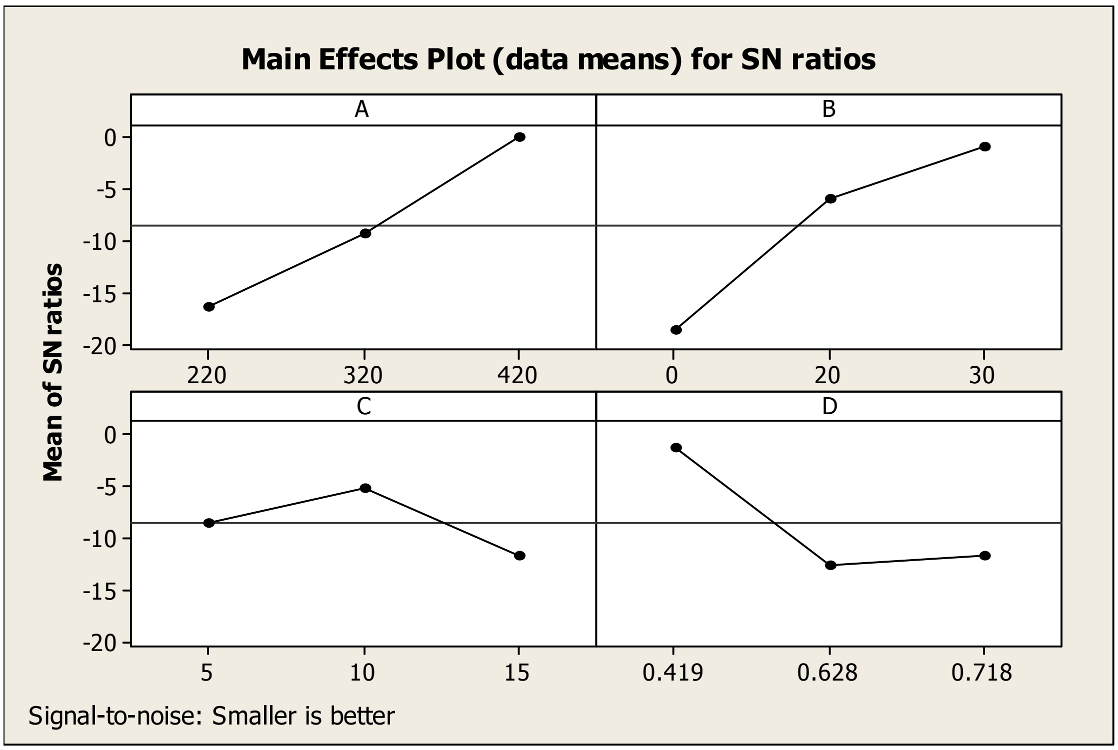


Fig.4.19. Effect of control factors on erosion rate

Table 4.11 gives the signal to noise response table which Shows that as far as the minimization of erosion rate is concerned; factors B, A and D, in this order, have significant effect on abrasive wear of the composites whereas factor C has the least or negligible effect. From this response table, it can be concluded that among all the factors, filler content is most significant control factor followed by abrasive grit size and sliding velocity while normal applied load has the least effect on abrasive wear of the epoxy resin composite. Analysis of the result leads to the conclusion that factor combination of A3, B3, C2 and D1 gives minimum specific wear rate as shown in fig. 4.19. The effect of abrasive grit size, applied load and sliding velocity on abrasion wear of all composites and neat epoxy (i.e. the matrix material) is evaluated in detail and the results are presented in fig 4.20 - fig.4.24.

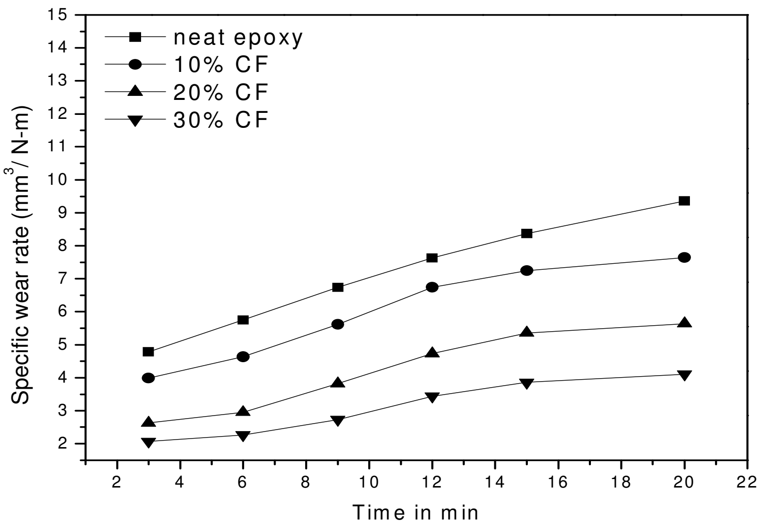


Fig .4.20. Specific wear rate of feather fiber reinforced epoxy composite (abrasive paper size 220µm, load 5N, velocity 0.718cm/sec)

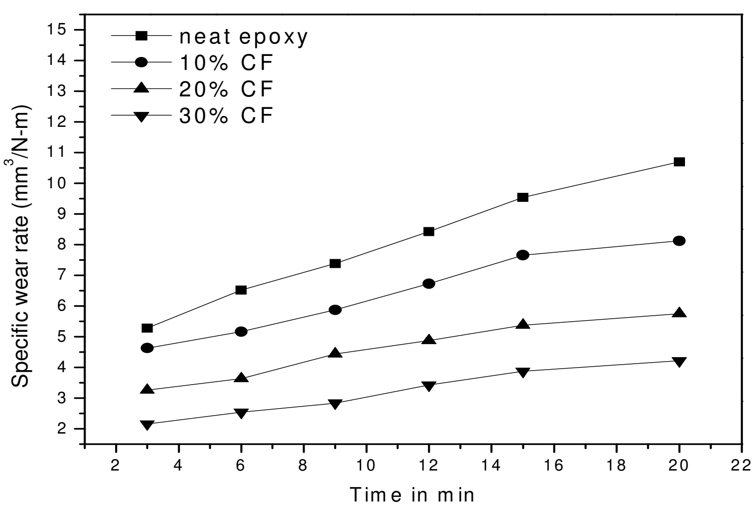


Fig. 4.21. Specific wear rate of feather fiber reinforced epoxy composite (abrasive paper size 220µm, load 10N, velocity 0.718cm/sec)

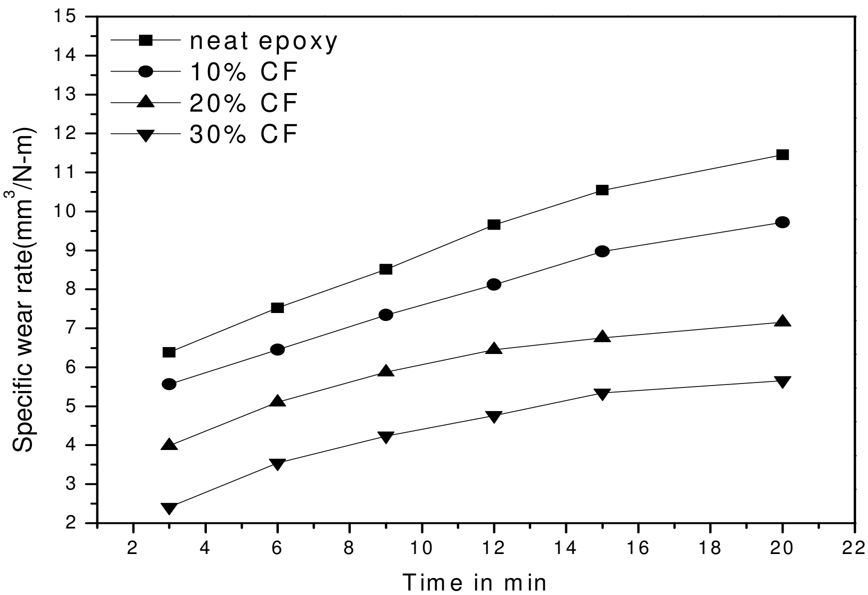


Fig.4.22. Specific wear rate of feather fiber reinforced epoxy composite (abrasive paper size 220µm, load 15N, velocity 0.718cm/sec)

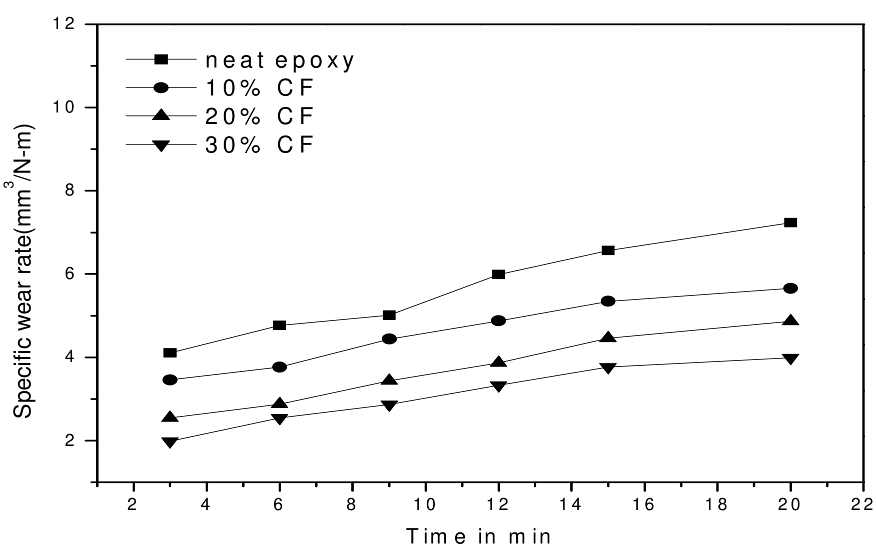


Fig.4.23. Specific wear rate of feather fiber reinforced epoxy composite (abrasive paper size 320µm, load 15N, velocity 0.718cm/sec)

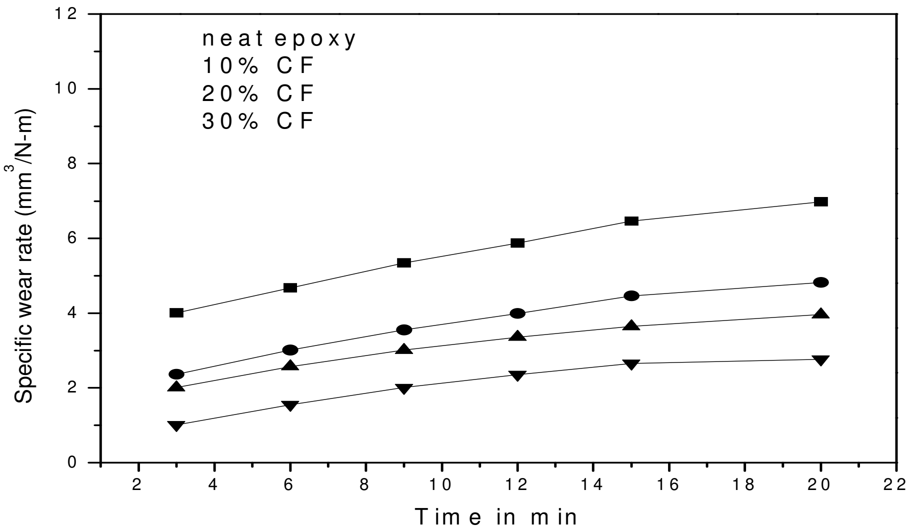


Fig.4.24. Specific wear rate of feather fiber reinforced epoxy composite (abrasive grit size 420µm, load 15N , velocity 0.718cm/sec).

From fig.4.20 to 4.24 gives specific wear rate of feather fiber of different wt% (i.e. 0%, 10%, 20% and 30%) epoxy composites at different condition it can be said that, cumulative mass loss decrease with increase in wt% of feather fiber content. It is interesting to note that while the specific wear rate increases almost exponentially with the increase in sliding velocity, it is reduced with increase in the applied normal load irrespective of the filler content. The presence of short chicken feather fibers seems to have helped in restricting the mass loss from the composite surface due to sliding wear. It is also found that the specific wear rate is gradually decreasing with the short chicken feather fibers content in the epoxy matrix indicating an improvement in the wear resistance of the composite.

4.3.4 Application of ANN Analysis

In the present analysis, the abrasive paper size, fiber content, normal load and sliding velocity are taken as the four input parameters. As already described, each of these parameters is characterized by one neuron and consequently the input layer in the ANN structure has four neurons. The database is built considering experiments at the limit ranges of each parameter. To train the neural network used for this work, about 45 data sets obtained during dry sliding wear trials on different composite samples are considered. Different ANN structures with varying number of neurons in the hidden layer are tested at constant cycles, learning rate, error tolerance, momentum parameter, noise factor and slope parameter. Based on least error criterion, one structure, shown in Table 4.12, is selected for training of the input-output data.

Input Parameters for Training	**Values**
Error tolerance	0.001
Learning rate (ß)	0.001
Momentum parameter(α)	0.01
Noise factor (NF)	0.5
Number of epochs	10,000,000
Slope parameter (£)	0.4
Number of hidden layer neuron (H)	12
Number of input layer neuron (I)	4
Number of output layer neuron (O)	1

Table.4.12. Input parameters selected for training

The learning rate is varied in the range of 0.001- 0.1 during the training of the input-output data. Neuron number in the hidden layer is varied and in the optimized structure of the network. The number of cycles selected during training is high enough so that the ANN models could be rigorously trained (as already been described in chapter-2). Seventy five percent of this data is used for training whereas twenty five percent data is used for testing while implementing the ANN protocol.

Expt. No.	Sp. Wear Rate (Experimental) (mm^3/N-m)	Sp. Wear Rate (ANN Predicted) (mm^3/N-m)	Error (%)
1	8.225	8.658	5.264
2	5.753	6.025	4.727
3	4.723	4.896	3.662
4	8.758	7.853	1.033
5	2.254	2.156	4.347
6	2.291	2.196	4.146
7	6.258	5.869	0.814
8	2.759	2.658	3.660
9	1.058	1.069	1.039

Table.4.13. Comparison of experimental results with ANN predicted values

Table.4.13 shows the comparison between the experimental and the ANN predicted results. The errors associated in each test run with respect to the experimental results are also given in the table 4.13. It is observed that the error in ANN prediction lies in the range of 0-6% which establishes the validity of the neural computation.

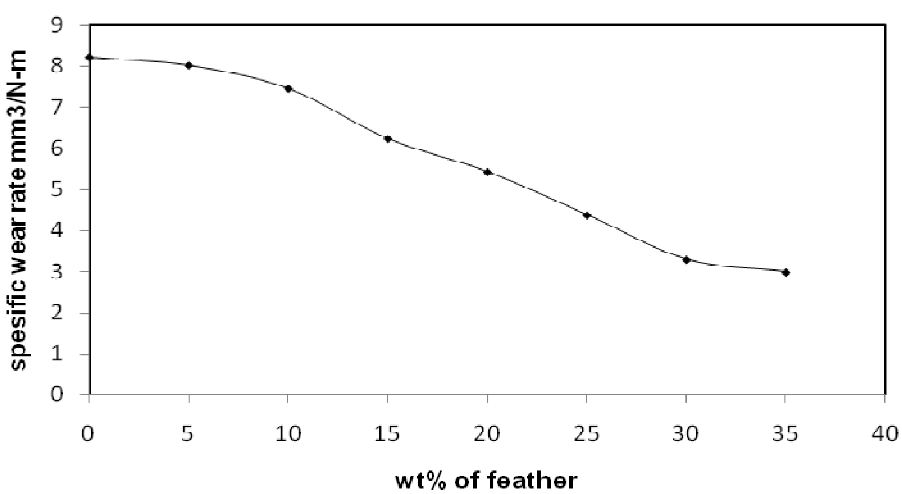


Fig.4.25. ANN predication on abrasive wear of different wt % of feather fiber reinforced epoxy composite.

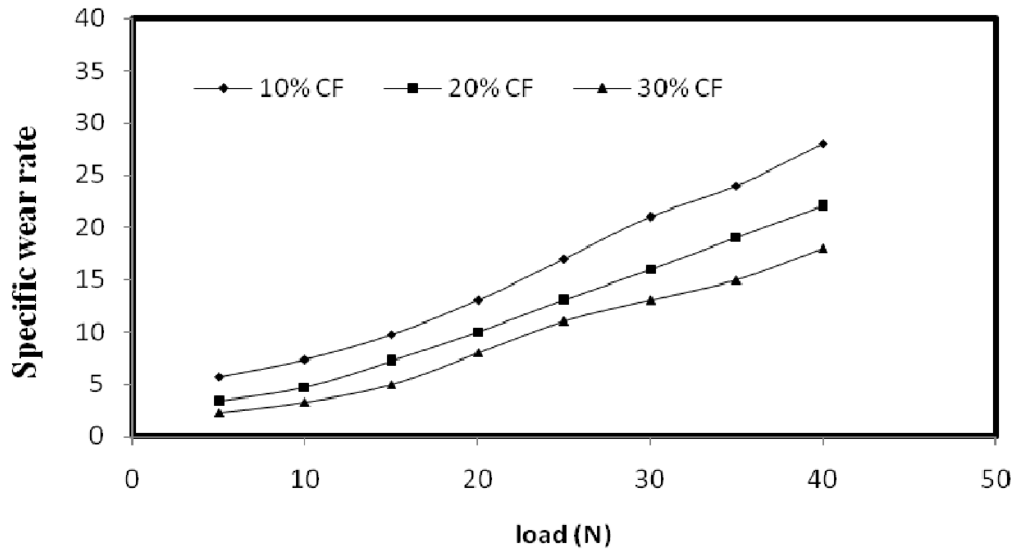


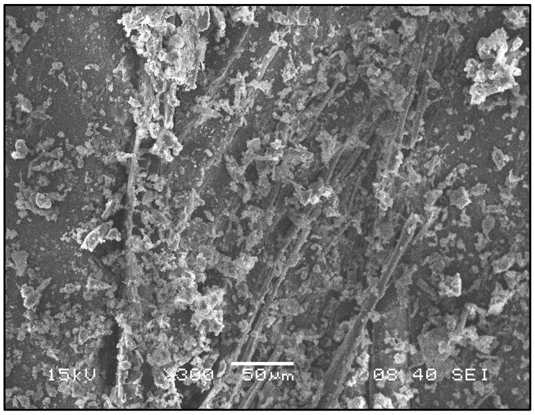
Fig.4.26. ANN predication on aspecific wear rate of feather fiber reinforced epoxy composite.

Fig 4.25 and fig 4.26, show the specific wear rate of father fiber reinforced epoxy matrix composite by ANN, which envisages that the specific wear rate decreases with increase in wt% of feather fiber and increases with applied normal load.

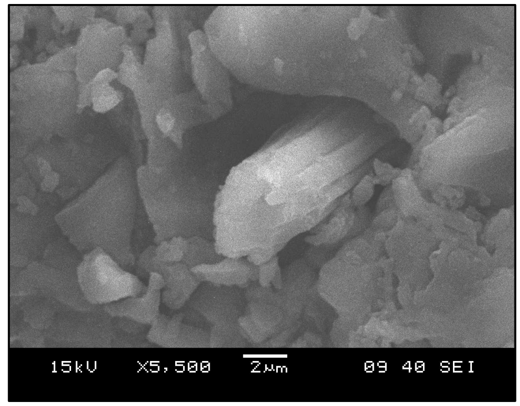
A simple framework for a physically based model for abrasive wear in ductile composites reinforced with a hard second phase is presented based on the salient mechanisms of sliding wear, namely plowing, cracking at the matrix/reinforcement interface or in the reinforcement, and particle removal **[221]**. While the torsional and out-of-plane particle pull-out mechanisms are certainly likely, this contributions to the overall wear rate are expected to be secondary. Critical variables describing the role of the reinforcement are identified in terms of the relative size of the reinforcement, the depth of plowing and the toughness of the matrix/reinforcement interface or the reinforcement.

In our investigation, with increase in the amount of reinforced phase i.e. chicken feather the hardness is improved which might restrict the wear rate. With increase in applied load, the ploughing mechanism might be dominating for material removal hence increase the wear rate.

4.3.5 Surface Morphology



(a)



(b)

Fig.4.27. SEM micrographs of the worn composite surfaces

The typical surface morphology of the abraded specimen is shown in fig.4.27. Abrasive particles removed the part of the fibres by delaminating and micro-ploughing mechanism. In present sample, the abrasive particles have slided and has led to the micro cutting of fibres and matrix. Fig.4.27 (a) clearly shows the wear track and cut fibres on the wear track. Wear process mainly due to the micro cutting mechanism The cross sections of vascular fiber bundles are clearly visible in Fig. 4.27(b), which shows the flower type geometry and diameter of vascular bundles. At some places fibres are reserved and remained embedded in the matrix. In this case, fibres geometry resists the flow of asperities and removal of debris. The cross sections of fibres come in contact and due to micro-cutting and micro-ploughing of the cross sections debris produced along with the matrix present between fibres, caused formation of wear track. Matrix fibre de-bonding is also observed in Fig.4.27 (a) and (b). This de bonding would have occurred due to the heat generation during sliding. This causes volume mismatching due to difference in thermal expansion co-efficient of fibres and matrix.

Chapter 5

CONCLUSIONS

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5.1. Conclusions

The experimental investigation and statistical analysis on feather fiber reinforced epoxy matrix composites has led to the following conclusions:

1. Chicken feather fibers (barbicels) bears high aspect ratio and hence are good reinforcement material for fabrication of randomly oriented short fiber reinforced epoxy composites. By incorporating feather fiber, density of the composites decreases and possess very low amount of porosity. However, Flexural strength and hardness of these composite increases with wt% of feather fiber, but not aggressively.

2. The FTIR spectroscopic analysis of the feather fiber reinforced epoxy composites shows that the formation of hydrogen bonds occurring at the fiber-matrix interface between the oxygen atom of the epoxy and hydrogen atom of the polypeptide chain of keratin is responsible for improving interface bond strength of these composites.

3. A new low-k material is developed from renewable resources using CF. The new low-k composite is a natural, bio-based and environmental-friendly material. The k-value is found to be in the range of 4.5-1.7 depending on the CF weight fraction and temperature conditions. The k-values are lower than those of a conventional semiconductor insulator material viz. silicon dioxide, epoxies, poly imides, and other dielectric materials.

4. These composites have adequate potential for applications in highly erosive and abrasive environments. Although they exhibit poor strength their wear performance shows significant improvement with wt% of short feather fiber reinforcement. Both erosion and abrasive wear of these composites can be successfully analyzed using Taguchi experimental design scheme.

5. Erosion wear of feather fiber reinforced epoxy composites are carried out by Taguchi L_9 design with four factors and three levels. It can be concluded that among all the factors, feather fiber content is most significant control factor followed by impingement angle and impact velocity while erodent size has the least effect on erosion of the composite. Using ANN analysis technique, the erosion wear rate beyond the experimental domain range could be predicted.

6. Abrasive wear of feather fiber reinforced epoxy composites are carried out by Taguchi L_9 design with four factors and three levels. It can be concluded that among all the factors, filler content is most significant control factor followed by abrasive paper grit size and sliding velocity while normal applied load has the least effect on abrasive wear of the epoxy resin composite. Using ANN analysis technique, the specific wear rate beyond the experimental domain range could be predicted.

7. These low strength feather fiber reinforced composites can be useful as coatings on curb slurry carrying pipes where erosion and abrasion is the measure factor for failure not the strength of the coating material/composite.

8. As a whole it can be concluded that, the composite with chicken feather fiber filler addition, improves the tribological behavior by 10-15% than that of the matrix material. A low cost composite could be processed and pollution caused by chicken feather can be prohibited.

5.2 Recommendation for Future Work

The present work leaves a wide scope for future investigators to explore many other aspects of bio-fiber reinforced polymer composites. Some recommendations for future areas of research include;

- To increase mechanical strength of these composites for their use in different sectors can be studied.

- Environmental study of feather fiber reinforced polymer composites i.e. the effect of different environmental conditions like alkaline medium, acidic medium, freezing temperature etc. on the properties and/or degradation of these composites is to be evaluated.

- Possible use of other fibers/flakes obtained from bio-wastes in the development of new composites.

- Other polymers can be tried as the matrix material for fabrication of poultry feather reinforced composites.

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Research Publications:

1. Nadiya Bihary Nayak, S.C.Mishra and alok Satapathy "Investigation on Bio-waste Reinforced Epoxy Composites" *Journal of Reinforced Plastics and Composites;* Online First, published on February 25, 2009 as doi: 10.1177/0731684408100740.

2. Nadiya Bihary Nayak, S.C.Mishra "An Investigation on Dielectric Properties of Chicken Feather Reinforced Epoxy Matrix Composite" *Journal of Reinforced Plastics and Composites;* DOI: 10.1177/0731684409356610